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MIL-HDBK-17

POLYMER MATRIX COMPOSITES

COORDINATION GROUP

Twenty-Ninth Meeting

29 - 31 March, 1994 Monterey, CA

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PROCEEDINGS OF THE TWENTY-NINTH MIL-HDBK-17 COORDINATION GROUP MEETING

MONTEREY, CALIFORNIA

29 - 31 MARCH 1994

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NOTE

The data contained in these proceedings should not be used for design purposes. This information was presented at the 29 - 31 March 1994 MIL-HDBK-17 meeting for discussion purposes only. The material contained in these proceedings may be subject to export control.

BERNIE HART
U.S. Army Materials Technology Laboratory
Coordinator, MIL-HDBK-17

1. MIL-HDBK-17 COORDINATION GROUP MINUTES

Gary Hagnauer opened the meeting by welcoming the participants and reviewing the scope of the handbook.

The working group chairmen met on Monday afternoon. The activities of that meeting were summarized with a review of agenda. The function of meeting was to promote coordination, avoid duplication of effort, promote communication, and plan the remainder of week. The development of agenda items was highlighted. Co-chairmen's and working group chair's responsibilities and the function of the secretariat were reviewed.

The next MIL-HDBK-17 meeting is scheduled for September 20-22, 1994 at the Fairmount Hotel in New Orleans:

Executive (working group chairs) session	Mon, Sept 19	1 - 5
Working group sessions	Tues, Sept 20	8 - 5
	Wed, Sept 21	8 - 5
General session	Thurs, Sept 22	8 - 12
Intersociety forum	Thurs, Sept 22	1 - 5

Joe Brennan has taken a leave of absence from ARL. Bernie Hart will be the new MIL-HDBK-17 Coordinator.

WORKING GROUP REPORTS

BRAIDING - Phil Wheeler

Braiding orientation code tables are under development. Approaching weave notation has been postponed. The agenda item on braiding taxonomy was closed at the last meeting. Buddy Poe presented braiding test methods and a related handbook section will be developed. A reference for braiding terminology reference has been identified. The possibility of merging Braiding and Filament Winding working groups was raised; the decision will be made off-line.

DATA REVIEW - Bob Pasternak

Changes to Volume 1 were reviewed. The working group recommended that data documentation and normalization be moved to Chapter 2 and that Section 8.4 be moved to Volume 2. The format for presentation of stress-strain curves will be confirmed by the next meeting.

89-01 Documentation of data review - draft to be reviewed prior to next meeting
90-15 Real world statistics simulation - IM7/8552 database to be provided for next-meeting
93-09 Normalization review

Data for AS4/3502 unidirectional tape and AS4/3502 5HS fabric were reviewed and accepted conditionally.

FILAMENT WINDING - Terry Vandiver

The agenda item on wet winding will be dropped since there is not enough information to warrant inclusion of this topic in the handbook. Definitions of terms related to filament winding are being reviewed. The inclusion of netting analysis will be a new agenda item. Section 6.7 which includes the testing matrix is being revised to reflect the approval of military and ASTM standards.

GUIDELINES - Joe Soderquist

Ed Wu, Naval Postgraduate School, presented the Academic Review. Gary Hansen introduced a new activity on alternate material supplier compatibility. Work at the Naval Research Lab on the use

of an energy dissipation function to simulate the structural response of damaged composites was presented by Bob Badaliance. A presentation was made by Michele Thomas on dent depth relaxation and how it affects inspection intervals. A new activity is being started in this area. Louis Anquez presented a new compression test method developed as a result of a round robin in Europe.

The reorganization plan for Volume 1, Chapter 2, was presented by Rich Fields. Margaret Roylance provided a status report on the User's Guide. Paul Lagace resolved the revision of the laminate strength and failure sections in Volume 3. Design of experiments support for ASTM/ISO round robin was requested by Rich Fields. The status of regression code was presented by Mark Vangel. A task group of Mark Vangel, John Adelmann, Bob Pasternak, Scott Reeves, and Crystal Newton was established to address different pooling scenarios prior to next meeting. Concerns regarding the material operational limit (MOL) will be addressed by the Guidelines and Testing working groups.

HARMONIZATION - Crystal Newton

The primary emphasis of the harmonization working group session on Wednesday was planning for the revitalization of the Intersociety Forum. Letters inviting participation in the Intersociety Forum at the next meeting will be sent to organizations involved or interested in standardization and composite materials. One agenda item on a review of the UK handbook is being addressed by the working group. A presentation on that handbook is anticipated for the next meeting.

MATERIAL & PROCESSES - Ted Kruhmin

Two sections will be added to Volume 3, Chapter 2, in response to the Initiative on fiber architecture, material forms, and manufacturing processes. This will close the related agenda item. The new chapter in Volume 1 for materials and processes information has been withdrawn based on the planned inclusion of that information in Chapter 2. Sections 2.2.2.2 and 2.2.2.3 in Volume 3 have been combined and submitted for coordination group review. The agenda item on fabrication (92-05) is being closed. The caveat for ozone-depleting chemicals (93-21) is being added to Chapter 1. A revision of the definition of "batch" is under consideration. "Lot" is preferred in industry. New terms such as "mix" and "master mix" will be defined.

STATISTICS - Mark Vangel

The code for developing design allowables using regression, REGTOL, is available in a preliminary version for review. A program titled DATAPLOT is available from NIST. Plans are being made to incorporate MIL-HDBK-17 procedures into DATAPLOT. Criteria are being established for batch acceptance. New business includes data pooling using REGTOL. Magdy Riskalla presented Adjusting F-Test for Correlated Data.

STRUCTURAL JOINTS - Peter Shyprykevich

To promote harmonization with ASTM D-30, two bearing methods have been converted to ASTM format by Rich Fields. Data documentation requirements sections to go into 7.2 and current 8.3 are being developed by Scott Reeve. Hui Bau presented results on fastener failures in laminated composite bolted joints. The outline and drafts of sections for Volume 3, Section 5.2, Mechanically Fastened Joints are being reviewed. A draft of an adhesive test method is being reviewed.

SUPPORTABILITY - Jerome Connolly

The working group established a vision statement A new table of contents has been developed with four sections out for working group review. A presentation was made by Peter Shyprykevich. The working group is developing reference list for supportability.

TESTING - Rich Fields

Reorganization of Chapters 4 and 6 has been approved. Information on failure modes is being added to Volume 1, Section 6.6, and a major re-write of Section 6.6 is underway. Matrix test methods

for Chapter 4 will be addressed. To include multi-axial testing in the handbook, a brief section will be written for Chapter 6 which references Volume 3, based on a recommendation by Gene Camponeschi. As part of the consideration of shear strength in coordination with ASTM D-30, the selection of the point/method for intermediate strength was discussed. A shear workshop is being sponsored by D-30 in May. A gas pycnometry draft is under review and transducer selection information is being considered.

The MIL-HDBK-17 list of agenda items was reviewed by Crystal Newton. Changes were approved by the Coordination Group. Working group chairs were reminded that agenda item descriptions are being requested.

Joe Soderquist led the voting for the selection of the site for the next meeting. The first choice is the Carson City/Lake Tahoe area. The second choice is San Antonio.

The general session was adjourned at 11:30.

2. WORKING GROUP REPORTS

Braiding
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. Agenda item 90-05: Braiding Orientation Codes Barry Pickett had written an outline for this topic several meetings ago. The group reviewed Barry's outline at the Alexandria VA meeting and received it quite well. Barry will rewrite the outline so that it is in a form that can be submitted as "yellow pages". The group will critique the draft at the next working group meeting. This agenda item was tabled until the next meeting because Barry could not make it to the Monterey meeting.

2. Agenda Item 91-09: Weave Notations It was recommended at the last meeting that the Materials and Processing group should retain this item.

3. Agenda Item 91-11: Braiding Taxonomy This agenda item has been closed.

4. Agenda Item 92-03: Braiding Test Methods A presentation was given by Mr. Buddy Poe on "NASA Textile Mechanics Work-in-Progress For 2-D Braids". Buddy volunteered to write his work in a consolidated form that can be included into the handbook. Buddy will fax a copy to the Braiding Chairman so that it can be submitted as "yellow pages". The group will review Buddy's write up at the next meeting.

5. Agenda Item 92-04: Braiding Definitions A NASA report "Illustrated Glossary of Textile Terms for Composites", by Christopher M. Pastore, was briefly reviewed. It was decided that the group will bring the report home and review the glossary terms to decide what terms should be included in the handbook. Although this agenda item has been closed, the group will still add new definitions as they are identified.

6. The possibility of combining the Braiding working group and the Filament Winding working group into a single group was briefly discussed. The driving force behind this was the low attendance in each of the groups.

Attendees

Mr. Mark Derstine, Atlantic Research Corp.
Mr. Clarence Poe, NASA Langley Resh. Center
Mr. Curt Davies, Gulfstream Aerospace
Mr. Ted Kruhmin, B.P. Chemicals
Mr. Phil Wheeler, Benet Labs

Data Review
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. The revision to Volume 1, Section 8.4.2, Organization of Data in the Handbook, was accepted with one editorial change and has been submitted for the "yellow pages".

2. Volume 1, Section 8.4.3, Sample Tables, will be reformatted with the help of the Secretariat to make it a more useful section. Distribution to the group is expected prior to the Fall meeting.

3. The group agreed to the recommendation that both Section 8.4.2 and 8.4.3 be moved to Volume 2. This recommendation was presented at the Coordination Group meeting and no negative comments were received.

4. Ron Bogaard offered to prepare sample graphs to use in Figure 8.3.5, Thermal Properties as a Function of Temperature, which is presently blank. An attempt will be made to circulate these to the group members prior to the Fall meeting.

5. The open agenda items were reviewed.

   Item 89-01 Documentation of the Data Review Process- Crystal Newton provided the chairman with a rough draft for this document. I will work with her to update this draft for presentation at the Fall meeting in New Orleans.

   ACTION ITEM: Generate draft on data review process for presentation at Fall meeting. (Newton/Pasternak, preliminary review by Spiegel and Kruhmin)

   Item 90-15 Real World Statistics Simulation- Item closed at Coordination Group meeting based on comments by Guidelines and Statistics that it was now covered in other agenda items.

   Item 93-09 Normalization of Data- John Adelmann provided a short presentation on the results of his preliminary investigation using the normalization techniques in the Handbook on data from various material systems. His findings, although sometimes the opposite of those that caused this investigation to be undertaken, showed that further study of additional data is warranted.

   ACTION ITEM: Continue investigation and provide recommendations on rewrite of Section 8.1.3 Normalization. (Adelmann, input from Fields and Kruhmin)

6. Candidate data for AS4/3502, both tape and 5-harness satin weave, was reviewed and found to be acceptable for submittal to Coordination Group review after the verification of several items. A sufficient number of batches were included to allow most properties to be "fully approved" data.

Attendees

John Adelmann, Sikorsky Aircraft
Eric Argent, Grafil Inc.
Tom Bitzer, Hexel
Ron Bogaard, Purdue University

Edward Clegg , US ARL-MD
Rich Fields, Martin Marietta Orlando
Denise Hambrick, Pratt & Whitney
Gary Hansen, Hercules
Bernard Hart, US ARL-MD
Tom Kipp, PDA
Ted Krumin, BP Chemical
Crystal Newton , MSC
Bob Pasternak, US ARL-MD
Tom Preece**, Callaway Golf
Steve Sanders , US ARL-WTD
Barry Spigel, Southwest Research Institute
Michael Stuart, CYTEC

Filament Winding
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. Filament Winding Working Group (FWWG) Co Chairperson, Terry Vandiver, opened the meeting and reviewed the agenda. The minutes of the last meeting were reviewed and approved as written.

2. Agenda Item 91-16: Wet Winding This agenda item was discussed in detail and it was decided that the effort amounted to a number of terms that should be included in Volume 1, Chapter 1, Section 1.7.

3. Review Definitions in Section 1.7, Chapter 1 Volume 1 for Terms Specific to Filament Winding Each attending member agreed to survey the definitions section for any terms specific to the filament winding process and present to the FWWG the next meeting.

4. Inclusion of Netting Analysis in MIL-HDBK-17 Netting analysis was discussed and it was decided that the FWWG would prepare a section on netting analysis and present it to the coordination group for inclusion in the next "yellow pages" review. The group also discussed that netting analysis would be a starting point in the design of filament wound pressure vessels and that more comprehensive analysis should follow.

5. Agenda Item 93-12, Rewrite of Volume 1, Section 6.7 Terry Vandiver presented a rewrite of Volume 1, Chapter, Section 6.7 entitled FILAMENT WINDING MECHANICAL PROPERTY TESTS for a line by line review. The information will be adapted to the new chapter format as presented by Testing Working Co-Chairpersons John Adelmann, Sikorsky and Richard Fields, Martin Marietta and presented for FWWG review at the next meeting.

6. New Agenda Item Update of Table 6.7, Volume 1, Chapter 6 Since three Military Standards and three ASTM test methods have been approved it is time to update the filament winding test methods to determine uniaxial material properties for filament wound structures.

7. Discussion of Combining with the Braiding Working Group Attendance has fallen off dramatically at both the FWWG and the Braiding Working Group. The idea was entertained to combine the groups since both areas consist of unique methods of processing composite structures. It was decided that this idea would be presented to the general coordination group for comment. It was decided that the MIL-HDBK-17 Co-chairpersons would resolve this problem off line.

Attendees:

Seth Ghiorse, ARL-MD
Denise Hambrick, Pratt & Whitney
Tom Preece, Callaway Golf
Terry Vandiver, U.S. Army Missile Command
Philip Wheeler, Bene't Labs

Guidelines
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. Gary Hansen overviewed changes he would like to make to Section 2.8.2, Volume I, Qualification Guidelines and Requirements for Alternate Composite Materials to reflect; (1) changes made in the raw materials that make up the constituents of a composite, and (2) changes occurring during the manufacture of the individual constituents. Gary, Glen Grimes, Scott Reeve, John Pimm, and Mark Freisthler will determine the extent to which Section 2.8.2 should be modified to reflect Gary's concerns. Gary will have a draft revision of this section for review at the next meeting.

2. Agenda Item 93-17: Test matrix of high temperature composites - Doug Ward reviewed his proposed changes to Gordon Bourland's test matrix Table 2.4(b) and Sam Garbo's screening test matrix Table 2.8.1. These modifications reflect tests needed to evaluate the effects of isothermal aging and thermal fatigue cycling on high temperature composite materials. Ray Bohlmann will assist Doug in completing his write-up of this section which will be ready for review at the next meeting.

3. Buddy Poe overviewed the use of a fracture mechanics method to analyze discrete source damage in tension loaded structure. For well bonded fibers (no crack-tip damage), the method predicts tension strength with crack-like damage in terms of laminate moduli and fiber failing strain. For some thin laminates, the method must be modified to include damage progression at the crack tips to avoid excessive conservatism. The method can also be used to predict the increase in strength due to buffer strips and straps. Buddy will prepare a draft write-up of a section which discusses ways of analyzing tension loaded structure subjected to discrete source damage.

4. Professor Ed Wu of the Naval Postgraduate School provided an overview of his research activities on life prediction of composite material systems. A probabilistic approach using a micromechanics model of fiber rupture distributions and load transfer at the ends of broken fibers was described. Viscoelastic effects were included in the model as well as distributions (accumulation of) or combinations of adjacent fiber rupture. Use of the model, while numerically intensive, provided a significant advance in laminate life prediction (S-N) capability based on constituent (fiber and matrix) basic properties.

5. Bob Badaliance overviewed an approach to characterizing failure behavior and degree of load induced internal damage in composite materials and structure. The approach, developed at the US Naval Research Laboratory (NRL), is based on a systematic experimental procedure to observe response of composite materials subjected to multi-axial load environment. The energy dissipated by internal failure mechanisms is used as a measure of internal damage and is characterized by an energy dissipation function, which is determined by means of a deconvolution procedure using data produced by NRL's automated In-Plane Loader.

6. Agenda Item 91-08 Generic laminate characterization (Section 1-2) - A completely rewritten Section 2.7 was proposed for Volume I. This section documented a series of three test matrices covering unnotched, mechanically fastened joint, and impact damage strength data generation. Inputs from Aerospatiale (M. Thomas) and Sikorsky (S. Garbo) form the basis of the new draft which is being submitted for the Guideline Working Group (GWG) approval. The actual section number of this section will be determined by the reorganization ongoing in Item No. 13.

7. Agenda Item 93-18 Crippling (Section 3-4.7) - John Pimm (Vought) reviewed the draft provided by Al Dobyns (Sikorsky) on compression crippling. The section was modified to include prior handbook write-ups describing the crippling phenomenon. The revised draft was discussed and approved by the GWG and will be submitted for publication in the yellow pages. John Dixon voiced a concern about the completeness and adequacy of the entire section and volunteered to review the section and provide recommendations for the next meeting.

8. Michele Thomas reported on studies conducted by Aerospatiale which showed that dent depths can relax under a number of usage conditions, i.e., as a function of time, aging, thermal cycling, and mechanical load cycling. She reviewed Aerospatiale's approach at quantifying the effects of each of these parameters on dent depth relaxation. Michele also explained the approach Aerospatiale used in addressing the effect this newly discovered phenomenon had on the structural integrity and inspection requirements of in-service composite structural components.

   Michele indicated that this phenomenon has also been observed by researchers in Canada. She will prepare a short write-up that alerts readers of the handbook that dent depths can relax and the parameters that cause this relaxation. This write-up will be placed in the Damage Tolerance Section (Section 4.11.1 of Volume III) of the handbook.

9. Louis Anquez presented the results of a round robin of compression testing conducted in Europe. The large scatter in the test results led to the development of a new compression test specimen using a $(\pm 60_n/0_2/\pm 60_n)_s$ stacking sequence. This laminate forces failure in the 0 degree plies in the test section. The 0 degree plies fail by fiber microbuckling while the 60 degree plies remain intact. This results in delaminations occurring between the 60 and 0 degree plies on either side of the specimen. Compressive failure strains and stresses, using this specimen, were approximately 2% and 2400 mpa, respectively. These values are significantly higher than results obtained from traditional test specimens. Round robin results are still under study for design implications.

10. Agenda Item 90-11 Rule-of-thumb design/analysis guide - John Pimm provided a draft write-up introducing a new section, i.e., Section 9.0 in Volume III on Lesson Learned. The write-up discusses the characteristics of composites materials, e.g., elastic properties, tailored properties and out-of-plane loads, etc., that make composites different from metals. Following this introduction, this section will contain industry lessons-learned with the use of composite materials including the previously drafted 100+ rules-of-thumb. The draft write-up on the unique characteristics of composites was submitted to the GWG for review and comments by the next meeting.

11. This item on steam pressure delamination was not addressed at the meeting. Ray Bohlmann will have a write-up ready for discussion at the next meeting.

12. Sam Garbo summarized his rewrite of the proposed new Section 2.7 of Volume I at the combined GWG and Materials and Processes Working Group meeting. Agreement with his approach was received.

13. Agenda Item 93-23 Chapter 2 Organizational critique - Rich Fields overviewed his proposed changes, including proposed new sections, to the Table of Contents of Chapter 2 of Volume I. He provided a new outline draft based on modifications approved by the GWG. Rich, with the help of Crystal Newton, will reorganize Chapter 2 material to adhere to the revised table of contents organization. The reorganized chapter will be reviewed at the next meeting.

14. Ted Kruhmin reported on the status of the existing Section 2 in Volume III and proposed the creation of two new sections to describe; (1) processing methods, and (2) the effects of potential defects in material forms and processing methods on material properties. Existing handbook write-ups were felt to be adequate and the new sections will be scheduled for action by the M & P Working Group. Agenda Item 93-06 will be closed out by the new section initiative.

15. Margaret Roylance overviewed the status of the Users Guide she is developing for the handbook. A number of additional comments made by GWG members will be incorporated into the document. The Users Guide, modified to reflect the comments, will be published and distributed together with the handbook.

16. Agenda Item 93-13 Impact damage - This item was not addressed at the meeting. Larry Ilcewicz will have a draft write-up for discussion at the next meeting.

17. Agenda Item 93-04 Revision of specimen conditioning (Section 1-2.2/6) - This item was not addressed at the meeting. Rich Fields will have a draft write-up ready for review at the next meeting.

18. Agenda Item 92-02 Overall review of the handbook - The document continuity review comments developed by John Pimm and reviewed by Joe Soderquist were turned over to Crystal Newton for inclusion in the handbook, as appropriate. Several of the comments needing GWG input were discussed and dispositioned at the meeting. Crystal will see that these comments are included in the handbook.

19. Sam Garbo reviewed a previous initiative to collect available DoD/NASA structural data. The intent was to use the data to assess MIL-HDBK-17 guidelines issues. The GWG members were asked to suggest study topics which would be assessed for appropriate scope and interest. Sam will contact GWG members within the next six months in order to develop a study topics list for discussion in New Orleans

20. Agenda Item 93-11 Failure criteria revision - Paul Lagace overviewed an agreed upon rewrite of the Failure Criterion Section to reflect both Walt Rosen and John Hart-Smith's concerns. Modifications were made to the text (Zvi Hashin's approach) that currently exists in the handbook and a new section, i.e., a fiber failure approach (laminate level) was written. The new draft was accepted by the GWG for submittal to the yellow pages.

21. John Dickson reviewed an earlier proposal that MIL-HDBK-17 get involved with standardizing structural design procedures and validation testing. Initial efforts were proposed regarding identification of types of analysis, appropriate validation tests, available design procedures, and listing of existing computer codes. John volunteered to create a limited draft, of his choosing, as an example of what this effort might involve.

22. Agenda Item 92-02 Overall review of the handbook - Rich Fields delivered his document continuity review comments to Joe Soderquist at the meeting. Joe will review the comments and confer with Crystal Newton and the appropriate working group chairperson regarding their disposition.

23. A Boeing (Ms. Bau) overview of lessons-learned in planning experimental design development programs was presented. The principle observation was that early agreement on criteria is essential for any progress to be made on definition of specific test matrices.

24. Agenda Item 88-18 properties of joints - Don Oplinger presented a suggested revision to his draft on adhesive bonded joint analysis. The current draft is to be reduced in scope to approximately 40 pages. The draft will be completed by the next meeting.

25. John Hart-Smith provided a draft write-up on bond surface preparation for composite adherends to Don Oplinger for inclusion in Chapter 5, Volume III.

26. Mark Vangel reported on a useful statistical data and graphics analysis software code which is available through Dr. James Filibin at NIST. Mark is arranging to have his LEGNAV code included in this NIST code. Mark overviewod its capabilities and offered to arrange distribution of this software code to those interested after LEGNAV is added to it.

27. Rich Fields proposed that the GWG endorse participation in the ISO/ASTM effort by providing a prioritized list of characterization variables which impact data base values. The effort will first focus on tension test specimens. A design of experiments study will be used to evaluate the effects test methods variables have on test results. The Statistics Working Group will aid in this effort. The GWG endorsed the proposed effort. Volunteers named to assist Rich in this effort include, e.g., J. Adelmann, D. Adams, G. Hansen, et al. Rich will present the status of this initiative at the next meeting.

28. Agenda Item 94-08 Regression Analysis and pooling - Mark Vangel briefly overviewed the status of LEGNAV, the statistical computer code he developed. It was agreed that before the next meeting: (1) Mark will try and have LEGNAV in a format acceptable for inclusion in the handbook, including examples; (2) Gary Hansen will try and get his IM7/8552 data in a format acceptable to the data Review Working Group; (3) Mark, Crystal Newton, John Adelmann, Scott Reeve, and Bob Pasternak will develop a number of pooling scenarios; and (4) Mark will use Gary Hansen's data to validate LEGNAV.

29. Agenda Item 91 - 18 Incoming/Receiving mechanical property tests - Scott Reeve reviewed examples of the studies he and Mark Vangel are conducting to develop guidelines for establishing acceptance values for material receiving inspections. Scott will survey industry to identify the material acceptance test methods utilized, the acceptance values adhered to, and the rationale supporting these approaches.

Scott and Mark will recommend criteria, statistical procedures, develop guidelines for establishing acceptance values, and evaluate the effects of various acceptance value methods. A status of their work will be presented at the next meeting.

30. The agenda item dealing with determining basis values using data from several sources was not discussed at the meeting. This issue can be handled through use of Mark Vangel's LEGNAV program.

31. Crystal Newton presented a list of data documentation requirements that is proposed to be a minimum list of requirements for inclusion of data in the handbook. Crystal will evaluate the usefulness of this list by assisting Mark Freisthler in obtaining the needed documentation of the 767/757 data for inclusion in MIL-HDBK-17.

32. Han-Pin Kan presented his write-up explaining the need and usefulness of the building block approach to design and development testing. His write-up will be reviewed by the GWG for discussion at the next meeting. A new section will be established in Volume III for this write-up. It is anticipated that as examples of real world building block programs are identified, they will be written up and appended to Han-Pin's write-up as examples.

33. Paul Lagace suggested that a review of current damage resistance assessment methods be performed. In addition, he suggested that the GWG brainstorm new ideas for the purpose of this part of the proposed Section 2.7.X, Volume I. The GWG agreed and this will be accomplished as part of the ongoing review of the current draft, see Item 6 of the GWG minutes above.

34. Agenda Item 94-07 Revisiting MOL - John Adelmann brought to the attention of the GWG the fact that the current recommendation of defining MOL as 50°F below the wet T_g does not seem to agree with degradation rates of mechanical properties as a function of temperature. It was suggested that the Chapter 2 section on MOL be revisited, and possibly expanded to include a broader discussion of MOL and ways to define it. This might include mechanical tests, various methods of obtaining T_g, and other factors. John will provide an update on this issue at the next meeting.

35. Policy for accepting properties for the handbook obtained by "backing out" from crossply laminate tests, was discussed. The GWG decided that data that had been generated from crossply tests with the original intent of backing out unidirectional properties would be accepted, and the backed out properties so identified in the data pages of Volume II. Crossply laminate data generated with the intent of testing laminate properties will be published in Volume II as the laminate values, with no backing out. John took the action to write the verbiage to explain this policy, and will propose the proper placement in the document for such a statement.

36. Crystal Newton, Sam Garbo, and Joe Soderquist reviewed and updated the GWG agenda items. Crystal will continue to maintain the master list of agenda items for all working groups and modify this list to include the GWG agenda item changes.

Harmonization
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. The third meeting of the provisional Harmonization Working Group was called to order at 11:15 after a meeting of the task group planning the revitalization of the Intersociety Forum. The agenda for the meeting was reviewed and reorganized.

2. Minutes from the November 1993 meeting were approved as distributed.

3. The plans for the revitalization of the Intersociety Forum were discussed. The letter inviting participation in the forum was reviewed. The list of potential participants was also reviewed. The participants represent metal and ceramic matrix composite interests as well as polymer matrix composite interests.

4. Two actions items were established:

   - Gary Hagnauer will invite a presentation on the UK handbook for the next meeting.

   - Crystal Newton and Gary Hagnauer will pursue inviting the participants to the next meeting of the Intersociety Forum.

5. There being no other old or new business, the meeting was adjourned at 11:52.

Materials and Processes
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

The meetings of the Materials and Processes Working Group on Mar 29 & 30, 1994, were attended by nine participants. The March 29th meeting was chaired by Margaret Roylance, and the March 30th meeting was chaired by Ted Kruhmin.

During these meetings the Materials and Processes Working Group discussed several agenda items and topics generated at previous meetings. These are listed below, with the actions taken.

1. 94-02 Reorganization of Volume 3 Chapter 2

Action: This is a new agenda item established by the Working Group to strengthen the current Volume 3 Chapter 2. This approach was taken instead of adding a new chapter on Materials and Processing Issues to Volume 1, which had been discussed at the last meeting (agenda item 93-22). Since a reorganization of Volume 1 Chapter 2 is being considered by the Guidelines Working Group, and since Volume 3 already includes information on Materials and Processes, the Group decided that the best use of our resources at this time would be in clarifying the purpose of this existing chapter in Volume 3, and adding material which addresses the effects of processing and material variability on the measurement of composite properties.

Members of the Group from Bell were asked to rewrite the introduction to Volume 3 Chapter 2 in order to tie the purpose of the chapter to the goal of the Handbook as a whole. The introduction should make clear that this chapter is not meant to be just another mini-encyclopedia of polymer composites, but also addresses the significance of M&P issues insofar as they affect the measurement and analysis of materials properties.

To accomplish this, new sections need to be added to the material in this chapter. A new section 2.6 should discuss the process parameters which control composite material microstructure and properties, and a new section 2.7 should address the significance of changes and/or variations of constituent materials, processing and fabrication on composite properties. A new section 2.8 will cover writing of materials and process specifications (currently listed in the outline as 2.6).

Section 2.6 will include the material on Composite Cure Modeling written by Dan Ruffner which was in the minutes of the Alexandria meeting. The cochairs of the M&P Group were asked to develop a list of topics which should be included in 2.6 with advice from Dan Ruffner, and to generate an updated outline for Volume 3 Chapter 2. Seth Ghiorse was asked to read through the current Chapter 2 and do a continuity review. He was also asked to consider topics to be included in section 2.7.

2. 93-22 New Section in V1 Ch2 on Materials and Processes

Action: The title of this item has been changed to reflect the Group's decision, discussed above, to make this a new section in a reorganized Volume 1 Chapter 2, rather than a separate new chapter in Volume 1. The purpose of this section will be to point out the importance of M&P issues in test planning and to call attention to the more extensive material to be found on this topic in Volume 3.

3. 93-06 Fiber Architecture, Material Forms and Manufacturing Processes

   Action: The Working Group discussed Professor Wilkins new proposal for a funded project to explore the topic of controlling and characterizing variability in manufacturing of composites. It was concluded that this work is still in the research phase and is not ready for insertion into the handbook. The Group therefore recommended that this action item be withdrawn. Since some material on this topic is already included in Volume 3 Chapter 2, and more will be incorporated into the proposed new sections, work in this area will be continued under agenda item 94-02.

4. 92-05 Fabrication

   Action: All the open subsections in the Fabrication section (2.5) of Volume 3 Chapter 2 have been submitted to the yellow pages, so this item is closed.

5. 90-04 Guidelines for Materials and Processing Specification Preparation

   Action: This material will be included in the Handbook as Section 2.8 of Volume 3 Chapter 2, so this item is merged into the new agenda item 94-02. Dan Ruffner submitted some material on writing specifications which is included at the end of these minutes.

6. 91-21 Establish guidelines for qualification of composite materials (Joint with Guidelines)

   Action: In our joint meeting with Guidelines, Sam Garbo reviewed his write-up on this topic. He is continuing to revise this material, and it will be reviewed again at the next meeting.

7. 93-21 Ozone depleting chemicals

   Action: The group reviewed and made some changes to a write-up by Margaret Roylance for a new section entitled "Environmental Awareness" which addresses the issue of ozone depleting chemicals, and also includes a general health and safety statement. This section has been submitted to the yellow pages as Section 1.8 in Volume 3, as requested by the Coordination Group.

8. The M&P Working Group reviewed and revised two polyimide write-ups by Bob Smith. These are included in the yellow pages as Section 2.2.1.6 on Polyimide Thermoset materials, and a continuation of Section 2.2.2.2 on Amorphous Thermoplastic materials. Section 2.2.2.3, entitled Condensation-cure, was deleted.

9. During the general Coordination Group meeting Ted Kruhmin brought the attention of the Group to the fact that the definition found at the beginning of each volume of the Handbook for Batch (or Lot) is not consistent with the commercial supply of materials.

   Batch (or Lot) - For fibers and resins, a quantity of material formed during the same process and having identical characteristics throughout. For prepregs, laminae, and laminates, material made from one batch of fiber and one batch of resin.

   Although batch and lot may be used interchangeably for many applications, there are occasions when a batch would not properly be defined as a lot. The Materials and Processes Working Group will include discussion of this issue as an action item for the next meeting.

Material and Process Specifications D. Ruffner
McDonnell Douglas Helicopter Systems
Submitted to MIL-HDBK-17 29 April 1994

1. Purpose of Specifications

Requirements for materials and processes are frequently so specific and extensive, a special type of engineering drawing format was developed. Specifications are usually A-sized engineering drawings. They are part of the engineering package that defines a particular product, whether an airplane or a golf club. Material and process specifications are similar to each other, but do have some differing requirements.

1.1 Material Specifications

The primary purpose of material specifications is to control the purchase of critical materials. The properties and values contained in the specification will relate to, but not necessarily be identical to, the mechanical, physical and chemical properties that engineering uses for activities such as design and structure testing. The properties and values contained in the specification are used to assure that the material does not change substantially with time. This is especially critical for materials used in primary applications, and which have undergone expensive qualifications. Material specifications are included in relevant contracts, and are part of the purchase order requirements to purchase material.

1.2 Process Specifications

Process specifications establish the procedures which are required to control the end product. The more process dependent the materials and/or end product are, the more detailed and complex the process requirements. On the other hand, if there is a wide window of acceptable product produced by the process, the process requirements may be minimal. Composite and adhesive bonding process specifications are usually detailed because the materials are very sensitive to process variations, and the aerospace end item requirements are usually very stringent.

2. Format for Specifications

Most specifications follow a similar format, based on guidelines contained in documents such as MIL-STD-490 and DOD-STD-100. The sections of a material or process specification are generally as follows.

2.1 Scope

The first section is the scope, which generally describes the materials or processes covered by the specification in a few sentences. Also covered in this first section are any types, classes, or forms of the materials which are governed by the specification. For example, one material specification may cover several different thicknesses of the same film adhesive, each thickness being a different class. This section establishes the shorthand terminology, or callout, which is used to identify the material on other engineering and procurement documents. A process specification may cover multiple processes, such as anodizing, with minor process variations based on the type of alloy being processed. The process for each alloy would be covered by a different type.

2.2 Applicable Documents

The second section identifies all the other documents which are referenced within the specification. Testing procedures and other material or process specifications may be called out. A trade-off is made between a specification being self contained, and redundancy between multiple specifications for

similar materials or processes. These trade-offs are discussed in more detail in the Configuration Management section.

2.3 Requirements

The third section covers the technical requirements for the material or controls for the process. For a material specification, these requirements can include physical, chemical, and mechanical properties, shelf and work life, toxicity, environmental stability, and many other characteristics. The requirements can be minimum values, maximum values, and/or ranges. Sometimes it is only required that the data obtained from the test be submitted. Only the test result requirements are contained in this section. The test procedure used to obtain this result is covered in the fourth section. For a process specification, the controls required to ensure the product produced is consistent are specified.

2.4 Quality Assurance Provisions

The fourth section covers testing. Although it is required that all the requirements of the specification be met at all times, only a fraction of the tests are performed routinely. Receiving inspection testing is that which is performed each time a quantity of the material is purchased, or a lot of product is processed. Qualification testing usually involves testing to all of the requirements of the specification to ensure that the supplier or processor is capable of meeting the requirements, and is performed only once unless there is cause.

Sampling and the specific test procedure to be used to determine conformance to the technical requirements are contained in this section. Testing procedures can be critical. In most cases, the value obtained cannot be used unless the specific test used to generate the value is documented. Test results can change when test procedures change, even though the material itself has not changed.

Also important is the preparation of the test specimens. Test results can vary widely depending on the configuration and condition of the test specimens. The conditions under which the test is performed can dramatically change the results. Conditioning of the specimen prior to test is also important, such as exposure to elevated temperature and humidity prior to test.

Responsibility for the testing required is also delineated. The manufacturer may perform all the receiving inspection testing, or the user may perform additional testing upon receipt of the material. Required reports are defined, as well as requirements for re-sampling and re-testing if a requirement is initially failed.

Preparation for Delivery

The fifth section covers delivery requirements. Issues such as packaging and identification, storage, shipping and documentation must be established. Packaging is especially critical for temperature sensitive materials such as prepreg and film adhesive .

2.6 Notes

The sixth section is usually notes, although the sixth section format can vary substantially. Notes are additional information for reference, and are not requirements unless specifically stated in the requirements section.

2.7 Approved Suppliers and Other

The seventh and additional sections can include information such as what materials are qualified to the specification. This section may reference a separate document which lists the qualified materials.

Because of the substantial expense which can be experienced as a result of qualification, normally only materials which are currently qualified are used for production applications.

3. Specification Examples

Specifications in common use are generally released by industry associations or the military. Industry associations common to composite and adhesive bonded structure are SAE, ASTM, and SACMA. In addition, companies may develop their own internal specifications for materials or processes which are not adequately covered by industry/military specifications, or to protect proprietary information. Each has advantages and disadvantages.

3.1 Industry

AMS 3894

Carbon Fiber Tape and Sheet, Epoxy Resin Impregnated

AMS 3897 Cloth, Carbon Fiber, Resin Impregnated

AMS specifications are available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-001.

3.2 Military

MIL-P-9400 Plastic Laminate and Sandwich Construction Parts and Assembly, Aircraft Structural, Process Specification Requirements

MIL-T-29586 Thermosetting Polymer Matrix, Unidirectional Carbon Fiber Reinforced Prepreg Tape (Widths up to 60 Inches), General Specification for

MIL-A-83377 Adhesive Bonding (Structural) for Aerospace and Other Systems, Requirements for

Military specifications are available from DODSSP, Standardization Document Order Desk, 700 Robbins Ave., Bldg. 4D, Philadelphia, PA 19111-5094.

3.3 Company Specifications

4. Configuration Management

4.1 Company Controlled vs. Industry Military

4.2 Callouts

4.3 Revisions

Statistics
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. 91-06. REGTOL version 2.0 (preliminary) is now available to anyone who requests it from Mark Vangel. REGTOL was discussed both in working group and with Guidelines. There seems to be a consensus that this is a useful tool, but more work needs to be done in order to make the methodology accessible to users of the Handbook. In particular, work will be done on the following:

   (a) Improve user documentation. This means writing up more examples, enough to cover the most common data analysis situations.
   (b) Submit the technical foundation for the approach for publication.
   (c) Develop test methods for significance of fixed effects in mixed models (e.g., When can we pool over fabric strength in warp vs. fill directions?; When can we pool over fabricators?)
   (d) Analyze real data which has been submitted for inclusion in the Handbook.
   (e) Find a better name for the software than REGTOL.

2. 91-05. Batch vs. panel variability. The source of variability that we usually attribute to 'batches' is actually a combination of variability due to batches with variability due to panels. There is substantial evidence (from mixed-model analyses) that the between panel component can be larger than the between-batch source. This suggests that maybe we should test fewer batches and more panels. We must build a case over time from many data analyses before we can confidently make recommendations.

3. The DATAPLOT program of data analysis and graphics has been developed by Dr. James Filliben of NIST as an ongoing project over the last fifteen years. This large statistics package is available for a nominal cost. It was decided in the joint Statistics/Guidelines meeting that it would be worthwhile to add MIL-17 statistics capabilities to DATAPLOT, and then to make the code available to anyone who wants it. Hopefully, this can be done by the next meeting.

4. Discussion of the role of statistics in developing batch acceptance criteria. As a first step, Mark Vangel will analyze data on many batches of material from four sources made available to the working group by Scott Reeve, (Lockheed). Scott Reeve will attempt to survey the industry in order determine the approaches currently in use. Leonard Schakel will look in detail at relevant practices at 3M.

5. Magdy Riskalla, Vought, presented work that he has done on adjusting the usual ANOVA F statistic to take into account correlation in material properties due to the proximity of specimens on a panel. He has given notes to the group members for evaluation, and he will continue work on this problem, with a likely presentation at the next meeting.

6. Action on agenda items

   - Closed: 88-42 (inaction), 88-44 (inaction), 90-12 (Section approved), 90-15 (redundant), 91-14 (special case to be handled by REGTOL)
   - Tabled: 89-09, 91-13
   - Opened: 94-08

Attendees

Frank Gruber, G.E. Aircraft Engines
Magdy Riskalla, LTV Aircraft Products Group
Leonard Schakel, 3M Metal Matrix Composites
Mark Vangel (Chairman), National Institute of Standards and Technology

Structural Joints
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. Minutes of last meeting accepted as written.

2. Mr. Scott Reeve presented load-displacement curves from actual single-shear tests to determine the best designation for bearing yield. This was done as part of the effort of harmonization with the draft ASTM D-30 test methods. The Mil-Hdbk-17 calls out 0.04D offset as yield while ASTM D-30 requires reporting 0.02D offset. After examining Scott Reeve's data it was decided that the 0.04D offset is a good reporting point but it is not always the 'yield' point. Therefore, Mil-Hdbk-17 will remove the 'yield' designation in future revisions. Ms. Hui-Bau would like to be able to associate the proportional limit and yield point to matrix and fiber failure in a joint but the state of knowledge is not sufficient to do this. There was also some discussion to define the proportional limit between two predetermined displacement points to avoid starting point ambiguities and operator errors and make more amenable to electronic data reduction. No agreement was reached and the definition as in the hdbk still stands.

3. Scott Reeve presented his updated version on data requirements for Vol II (viewgraphs enclosed). While working on this section he felt there was a need to make some modifications to Sec. 7.2.5.5 which were discussed. All changes were approved and will be given to the Secretariat together with the revised Secs. 8.3, 8.4 and the appropriate Tables as yellow pages at the next meeting. One major addition was to include figures or photos of various failure modes to accompany Table 8.3.2.1. Scott's text is enclosed for comments from working group members.

4. Ms. Hui-Bau from Boeing made a presentation on " Fastener Failures in Composite Bolted Joints". She reported on her Boeing 777 experience of observing fastener failures before achieving full bearing capability of the composite. This occurred for thicker laminates and joint pack-ups. Joints with very thick laminates failed by bolt shear. Boeing developed a semi-empirical model to predict fastener head and/or tail failures for laminate thicknesses between laminate bearing failure and fastener shear failure. The methodology, based on examining functional dependence on parameters that drive these types of failures, showed excellent correlation with data. A copy of the presentation is attached.

5. Peter Shyprykevich presented several inputs for Sec. 5.2, Vol. III on Design and Analysis of Bolted Joints prepared by him, Gerry Flanagan, Don Oplinger, and Bemie Beal. Scott Reeve also prepared a section on design considerations. A copy of the submitted write-ups was given to the attendees and will be distributed to all working group members for comments. Also, Han-Pin Kan verbally outlined what he will include in his write-up on fatigue. His write-up and any comments on the existing write-ups are due by July 1,1994 to Peter Shyprykevich. A section on load sharing in a joint was assigned to Peter Shyprykevich and Don Oplinger.

6. The first draft of Sec. 7.3.1 Adhesive Characterization was presented by Peter Shyprykevich. It contains description of the Krieger Thick Adherend Test. Description of the tensile tests is yet to be written. A suggestion was made by Scott Reeve to include test matrices. There was also agreement that the tensile test for adhesives should be 'plug type', and that bonded joints tests should describe single and double lap joints with thin adherends. The draft of Sec. 7.3.1 is enclosed with the minutes to the members of the working group. Comments are due by the next meeting.

The following items were discussed in a joint meeting with Guidelines Working Group:

7. Don Oplinger presented a new revised outline of the long awaited Sec. 5.1,Vol III, Adhesive Joints. The section will be reorganized and shortened to about 40 pages, and will be ready for balloting into yellow pages at the next meeting.

8. Dr. John Hart-Smith prepared a write-up on preparation of adhesive joint surfaces. He forwarded this to Don Oplinger to inclusion in Sec. 5.1, Vol III (see above).

9. The rules-of-thumb action item was discussed by John Pimm from the Guidelines Working Group who was given the overall responsibility on this topic. This item has now been placed in a completely new chapter under the title of "Lessons Learned" . Ron Zabora is still tasked to coordinate his effort with him. Ms. Hui-Bau, Ron's substitute, made some general comments as to the contents and philosophy that will be used to come-up with acceptable rules-of-thumb for joints.

Attendees

Louis Anquez, Dassault Aviation
Ray Bohlmann, McDonnell Aerospace-East
Sam Garbo, Sikorsky Aircraft
Glenn Grimes, Lockheed Advanced Development
Bob Gurrola, Huck International
John-Hart Smith, McDonnell Douglas
Ludwig Lemmer, DASA, Military Aircraft
Don Oplinger, FAA
Scott Reeve, Lockheed Aeronautical Systems
Peter Shyprykevich, FAA
Michele Thomas, Aerospatiale
Hui-Bau for Ron Zabora, Boeing

Supportability
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

The meeting began promptly at 2:00 pm on March 30th and concluded at approximately 4:45 pm. At 3:00 pm Peter Shyprykevich, from the FAA, gave a short presentation on the ATA/SAE Commercial Aircraft Composite Repair Committee activities. Names of potential supporters on this committee were identified.

Attendance is improving with Teresa Marian (Advanced Composite Technology), Andrew Pearson (Transport Canada), Debra Wilkerson (Hexcel), Jim Fuss (NADEP, Cherry Point), Bud Westerman (Boeing), Mark Chris (Bell), and Jerome Connolly (Vought Aircraft Company) in attendance. Seven major tasks were accomplished: 1) The Vision Statement was agreed upon; 2) A new Table of Contents was drafted; 3) A growing list of potential supporters was added to and distributed; 4) A growing list of references was distributed; 5) A Reliability and Maintainability section was distributed for editing; 6) An Interchangeability and Replaceability section was distributed for editing and; 7) Additional assignments were made.

The Vision Statement and Table of Contents are included at the end of these minutes. The additional task assignments were predominately to produce draft write-ups for sections. Teresa Marian was assigned Inspectability and to produce a list of participant names, telephone numbers, and fax numbers. Bud Westerman was assigned overall section introduction and introduction to the Design for Supportability subsection. Material Selection will be produced by Debra Wilkerson. Leanna Redford and Jim Fuss were assigned Damage Tolerance and Durability. Jerome Connolly was tasked with producing a 3 year write-up plan and schedule, along with an updated Table of Contents.

An additional goal for the next meeting is to increase participation. To that end various organizations, committees and individuals are being approached for active support.

VISION STATEMENT

PROVIDE DESIGN ENGINEERS AND SUPPORT PERSONNEL WITH THE GUIDANCE NECESSARY TO COST EFFECTIVELY ENHANCE COMPONENT SUPPORT AND FUNCTIONALITY. IN KEEPING WITH MIL-HDBK-17 GOALS, ACTIVITIES WILL PRIMARILY FOCUS ON MATERIAL RELATED ISSUES.

CHAPTER 8. SUPPORTABILITY

Testing
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

Group Decisions Shown in Bold Italic
Coordination Group Agenda Item Numbers Lead Related Paragraphs

[Standing] John Adelmann called the meeting to order on 29 Mar 1994 at 0802 at the Monterey Marriott Los Angeles room. Rich Fields acting as Secretary. The planned agenda is shown as Attachment A. The minutes were moved for approval (Spigel/Moylan) and approved without discussion or change. The planned schedule was for Testing to meet all day on the 29th and from 800-1000 and from 1300-1400 on the 30th in a joint meeting with Guidelines. However at this meeting there is no need to meet with Guidelines, so the joint meeting will be canceled. Due to a conflict with Data Review on the 29th, John asked if there were any objections to truncating the first day's morning meeting at 1000, to resume at 1300. There were no objections. A sign-up roster was passed around and the results are shown as Attachment B; a total of 26 attended the Testing meetings. Some more time was spent scheduling presentations around conflicts with other working groups.

[Standing] John summarized the recent accomplishments of the Working Group, including a synopsis of the process of developing Handbook sections.

[No Item] John reviewed the new outlines for Chapters 4 and 6, which were approved at the previous meeting. It was proposed and ***agreed to implement the new outline of Chapter 4 with the writing that is underway***, so that a new Chapter 4 can be submitted to the Yellow Pages in its entirety.

[89-14] The Chapter 4 outline was discussed further and it was suggested and ***agreed to insert a section on matrix shear testing*** following 4.6.3 Compression. Don Adams agreed to draft this section, to coordinate with Paul Pittari who is covering the remainder of 4.6.

[89-14] Rich Fields summarized the status of Paul Pittari's write-ups on Chapter 4. Paul was unable to make this meeting but sent Robert Fidnarick in his place, who brought a copy of the draft on disk. Rich and Robert will work off-line to include the previous meetings comments into the draft.

[No Item] John Adelmann reviewed his addition to 6.6.1 regarding failure modes, based on the desires expressed at the previous meeting. The text was generally well received, but several comments were made. John will attempt to incorporate them overnight and present an update on the 30th (discussed further below).

[No Item] There was some discussion on the need for a reorganization of Chapter 7, which is complicated since the jurisdiction of Chapter 7 is not clear. The group felt that ***CAI belongs in Chapter 7***. The group also felt that ***Testing should have joint jurisdiction of OHT and OHC and that Chapter 7 is the appropriate place*** for these. The discussion was tabled pending a discussion between John and Rich and Peter Shyprykevich.

[92-01] John Moylan discussed the first revision of his CAI write-up, which was fairly complete as to original scope; however a lively discussion ensued that essentially expanded the scope to include mention of BVID and sandwich construction. John to further revise the draft, for critique by John Adelmann, Ray Bohlmann, and Don Adams.

The meeting was then adjourned at approximately 1000 and reconvened at 1307.

[93- 12 w/FW] Terry Vandiver presented his first draft on test methods for filament winding materials. These sections will be coordinated between the Testing and Filament Winding Working Groups. He will update this write-up and arrange to have it sent out for review to the core members of both groups by July 94.

[91 - 12] Margaret Roylance presented her first draft on Tg measurement. (Rich Fields to help check for relevant ASTM Standards. Scott Sendlein to check on ACS Standards.) Margaret will incorporate the comments in a second draft, including DMA Tg's on a material in both the dry and wet conditions. A paragraph on correlation of Tg method with the MOL value recommended by Guidelines in Chapter 2 will be removed from this section. Margaret will arrange to have the write-up sent out for review by 15 April 94. (Joe Soderquist has asked to be added to the list of reviewers for this.)

[94-new w/G] The concerns of the Testing Working Group about assessment of MOL will be brought up as an issue within Guidelines. The ***Testing Working Group feels that MOL is laminate application and loading condition dependent and that lamina/laminate/structural tests to determine MOL may, in some cases, be more appropriate than a Tg test,*** which is more qualitative than quantitative, as far as prediction of hygrothermal effects on structure.

[92-01] Ray Rawlinson presented his first draft on the out-of-plane tension testing subsection. Ray and Rich will incorporate this, with the comments, into the overall tension test section for review by July, 94.

[92-01] Sailendra Chatterjee presented his first draft on the Strain Energy Release rate test method section (based on notes by Kevin O'Brien). Only minor comments were received as no advance review was able to be made. This draft will be distributed for review prior to any further revision.

[91-25 w/TS] John Adelmann presented Gene Camponeschi's status on multi-axial testing of composites. The presentation reviewed the outline and content of Volume 3 Chapter 7 being written by the Thick Sections Working Group, with emphasis on Section 7.2.3 on experimental property determination. Gene's recommendations were 1) the Testing Working Group should review 3-7.2.3 and make comments to be passed on the Thick Sections Working Group, and 2) that a single paragraph be written in 1-6.x that acknowledges the topic of multi-axial testing and refers the reader to 3-7.2.3. Gene's write-up included a proposed paragraph. The ***Testing Working Group agreed with this recommendation (although the issue of the restricted scope of Volume 3 was later raised).*** John Adelmann to distribute 3-7.2.3 to the core members of Testing.

[Presentation] Don Adams presented a summary of test methods work he performed under an FAA contract. Don specifically addressed certain aspects of compression and short beam shear testing. The discussion of compression testing dealt with experimental and analytical differences between end-loaded and shear-loaded specimens and results obtained from several variations of a thickness-tapered specimen, using unidirectional tape. Regarding short beam strength, Don presented analytical and experimental results that explain why short beam strength decreases as 3-point span to thickness ratio increases, and why 4-point tests produce lower apparent strength than 3-point loading. The meeting then adjourned at about 1700.

[No Item] The meeting reconvened on Wednesday 30 Mar at 0805. John Adelmann reviewed changes to Section 6.6.1 covered failure modes based on yesterday's comments. After a minor change, there was a motion to approve (Pasternak/Spigel). No discussion; ***motion carried to approve the new Section 6.6.1.*** *(This was briefed at Coordination Group and there was a comment suggesting that the very first sentence be considered for re-wording to make it clear whether this was talking about pre-test post-test or both.)*

[93-08] Rich Fields presented a summary of ASTM D30 issues relating to material shear strength. D30 is deprecating the use of ultimate shear strength based on currently available methods and is soliciting opinions on other useful material comparison parameters; D30, in the interim, is emphasizing the use of an offset strength, currently being proposed at a 2000 microstrain offset, since the resulting value is in the vicinity of the onset of initial damage as observed in recent evaluations, plus the physical appearance of the stress-strain curve. The fact that it is the same offset as that popular in testing of aluminum alloys is coincidence. Other meaningful strength comparisons are still being considered by D30. Rich noted the organization of a shear strength workshop at the Montreal ASTM meeting in May.

[89-14] Seth Ghiorse presented his write-up on gas pyncnometry density measurement. The write-up itself was not reviewed, but Seth fielded a number of questions on his experience with the method and the pros and cons. The write-up will be reviewed by mail. Seth will evaluate a NIST density standard to be provided by Rich Fields, and will consider an experiment to evaluation the precision and bias of the method as a function of specimen volume.

Actions:

Closed:

- [91 -24] Crossply testing.

Continuing from previous meeting with no action:

- [No Item] Addition of discussions on laminate testing in new and existing sections due to new outline (Adelmann).
- [No Item] Disconnect in 6.1 Scope with current direction of Handbook (Fields).
- [93-14] Editorial changes to Chapter 5 (Fields).
- [88-47] Issues on transducer selection (Adelmann).
- [89-14] Void volume micrographic method (Adelmann). Johlmann to check on expertise at home shop for possible volunteer.
- [93-04 w/G] Chapter 2/6 conditioning update (Fields).

New actions resulting from the current meeting:

- [89-14] Adams: Draft 4.6.4 on matrix shear testing, coordinate with Paul Pittari, submit for review by July 94.
- [Standing] Adelmann: Gather copies of presentations for minutes.
- [No Item] Adelmann: Clean-up revision of 6.6.1 for submittal to Yellow Pages (see comment from Coordination Group).
- [Org] Adelmann: Coordinate Chapter 7 organization issues with Peter Shyprykevich and Rich Fields.
- [92-01] Adelmann: Pass fracture write-up on to O'Brien for review.
- [91-12] Adelmann: Pass Tg write-up to Soderquist.
- [Standing] Adelmann: Update list of core members.
- [Standing] Adelmann: Coordinate reviews with core group.
- [92-01] Adelmann: Provide copy of AMS 3903 bowtie test method to Fields.
- [91 -25 w/TS] Adelmann: Distribute copy of Thick Section testing write-up.
- [92-01] Chatterjee: No action until comments received on fracture write-up.
- [89-14] Fidnarick/Pittari: Update pertinent chapter 4 sections, coordinate with Ghiorse and Adams for submittal by July 94. Make density section applicable to solids in general for placement in Chapter 6.
- [Standing] Fields: Pass on recommendations to Coordination Group.

- [Standing] Fields: Complete and release minutes.
- [89-14] Fields: Make NIST density standard available to Ghiorse.
- [93-08] Fields: Report on actions of D30 shear workshop at next meeting.
- [92-01] Fields: Coordinate consolidation of tension write-up with Ray Rawlinson by July.
- [91-12] Fields: Check for ASTM standards relevant to Tg and pass to Margaret Roylance.
- [94-new w/G] Fields: Raise MOL issue with Guidelines.
- [89-14] Ghiorse: Update pyncnometry write-up; evaluate NIST density standard.
- [92-01] Moylan: Update CAI draft for initial review by Adelmann, Bohlmann, and Adams to provide broad direction on scope with regard to BVID and sandwich.
- [89-14] Pittari: See Fidnarick.
- [92-01] Rawlinson: Complete out-of-plane tension draft and coordinate with Fields.
- [91-12] Roylance: Assess state of early sections of Chapter 4; update Tg write-up and send to Adelmann by 15 April 94.
- [91-12] Sendlein: Pass ACS standards relevant to Tg testing to Margaret Roylance.
- [93-12 w/FW] Vandiver: Update Filament Winding write-up for review by July 94.

Meeting adjourned until September 94 at 1003 by John Adelmann.

Attendees

John Adelmann, Sikorsky A/C
Rich Fields, Martin Marietta Orlando
Ray Bohlmann, McDonnell Douglas Aerospace East
John Moylan, Delsen Testing Laboratories
Terry Vandiver, U.S. Army Missile Command
Bob Pasternak, U.S. Army Research Laboratory MD
Eric Argent, Grafil Inc.
Scott Sendlein, Pratt and Whitney FL
Denise Hambrick, Pratt and Whitney CT
John Townsley, McDonnell Douglas Aerospace
Robert Fidnarick, Grumman Aircraft
Tom Preece, Callaway Golf
Don Adams, University of Wyoming
Sailen Chatterjee, Materials Sciences Corporation
Tom Bitzer, Hexcel
Ron Bogaard, Purdue University
Michael Stuart, Cytec
Doug Ward, GE Aircraft Engines
Don Honaker, Touchstone Research
Seth Ghiorse, U.S. Army Research Laboratory MD
Ted Kruhmin, BP Chemical F&M
Gary Hansen, Hercules
Bob Gurrola, Huck International
Crystal Newton, Materials Sciences Corporation
Barry Spigel, Southwest Research Institute

Agenda and Meeting Goals

MIL-HDBK-17 Testing Working Group

AGENDA ITEM	GOALS FOR THIS MEETING
Approval of Last Meeting Minutes	--
Review of Last Meeting Accomplishments -- John Adelmann	1. Review items completed 2. Review status of ongoing items 3. Review status of ch. 3, 4, 5, 6, 7 outline revision
Section 4.3.3 through 4.6 Matrix Properties (Item 89-14) -- Paul Pittari	1. Review/discuss latest draft and obtain Working Group Approval 2. Submit for Coordination Group approval
Sections 4.2, 4.3.1, 4.3.2 Review -- Margaret Roylance	1. Consider Margaret's recommendations 2. Assign actions to complete
<u>Section 6.6 Revision (Item 92-01)</u>	
6.6.1 General -- John Adelmann	1. Review draft that incorporates references to ASTM failure mode illustrations
6.6.2 Tensile Tests -- Rich Fields/ Ray Rawlinson	1. Review out-of-plane draft by Ray Rawlinson/ Ray Bohlmann 2. Consider information on beam tests provided by John Adelmann 3. Assign actions to complete this section by next meeting
6.6.8 Damage Tolerance and Laminate Testing	
. Open Hole Tension/Compr. -- John Adelmann	1. Make final decision whether to address in ch. 6.
. Compression After Impact -- John Moylan	1. Review/discuss second draft and obtain Working Group approval 2. Submit for Coordination Group approval
. Strain Energy Rel. Rate - Sailendra Chatterjee	1. Review first formal draft 2. Provide author with specifics needed to finalize for next meeting
. Bearing Strength -- John Adelmann	1. Make final decision whether to address in ch. 6
Biaxial Testing (Item 91-25) -- Gene Camponeschi	1. Discuss recommendations on how to coordinate/combine with existing Thick Sections write-up 2. Make assignments needed to move forward
Section 6.7 Filament Winding -- Don Jaklitsch	1. Discuss recommendations/first draft of section rewrite in standard format 2. Provide author with specifics needed to make additional progress for next meeting.
Changes to Existing Sections Based on New Outline - John Adelmann	1. Identify changes needed in ch. 6 2. Make assignments as needed

Glass Transition Temperature (Item 91-12) – Margaret Roylance	1. Review first formal draft 2. Decide where section can be integrated into the Handbook (4.3.1, 5.5.4, 5.5.5, 6.3.1) 3. Provide author with specific direction for next meeting. 4. Make recommendations on section placement to Guidelines
Recommendations for Strain Gages vs Extensometers (Item 88-47) – John Adelmann	1. Review initial draft 2. Provide author with specific direction for next meeting
Failure Mode Examples (Item 88-48) – John Adelmann	1. Close out or continue based on section 6.6.1 action above
Prepreg Characterization - Charles Lee/Rich Fields	1. Report status of editorial changes in ch. 5
Void Volume Micrographic Method – John Adelmann	1. Report status of work 2. Define level of detail needed in section 6.3.3
Reporting and Use of Lamina Shear Strength – Rich Fields	1. Define the issue 2. Determine how, where, (and if) to address in the Handbook 3. Assign appropriate actions
Presentation on FAA Contract on Test Methods - Don Adams	1. Everyone listen attentively 2. Offer suggestions

Thick-Section Composites
Working Group Minutes
29 - 31 March, 1994
Monterey, CA

1. Six (6) participants attended the ninth (9th) meeting of the Thick-Section Composites Working Group (TSCWG). The meeting was held for a total of four (4) hours over a two-day period. Erich Weerth, TSCWG chairman, opened both working group sessions for business

2. After visitor introductions and the addition of new members the first order of business was to review the status and progress of unfinished action items. However, due to limited attendance, resulting from restricted travel budgets and schedule conflicts, the meetings focused on the restructuring of Volume III Chapter 7 in its entirety.

3. The Table of Contents for Volume III, Chapter 7 entitled Thick-Section Composites was restructured to incorporate four Demonstration Problems as well as Section 7.5 which discusses Process Analysis Methods for Thick-Section Composites.

4. The restructured outline of Volume III, Chapter 7, as approved by the Working Group in this and prior sessions, is presented as in the yellow pages for Coordination Group Review.

Attendees

Ray E. Bohlmann, McDonnell Douglas Aerospace - East
Sailen Chatterjee, Materials Sciences Corporation
Denise Hambrick, Pratt and Whitney
Don Honaker, Touchstone Research Laboratory
Tom Preece, Callaway Golf
Erich Weerth, ATAK, Incorporated

3. MIL-HDBK-17 AGENDA ITEMS

ITEM	*	SECTION	TOPIC
88-14		1-2	Table 2.5 for filament winding (Filament Winding)
88-18		3-5.1	Properties of joints (Guidelines)
88-42		3-4.6.6	Lamina-to-laminate analysis (Guidelines,Statistics)
88-44	T	1-8	Multi-batch Weibull analysis (Statistics) - withdrawn due to no action or current interest
88-47		1-6	Recommendations on strain gages vs. extensometers (Testing) - continued
88-54		3-4.6.6	Laminate-to-lamina analysis (Guidelines) - withdrawn due to no action or current interest
89-01		1-8	Documentation of data review (Data Review) - continued
89-08		3-3.4	Quality assurance - SPC (Guidelines) - transferred to Materials and Processes
89-09		1-8.3.7	Review of Stress-strain curve method (Statistics). - tabled
89-14		1-4.4	Mechanical test methods - matrix (Testing) - continued, approval anticipated at the next meeting
89-15	R	3-6	Structural reliability (Guidelines) - closed based on sections approved
90-03	R	1-8	Derivation of unidirectional properties from cross-reinforced tests (Guidelines) - closed upon approval of sections under review in the 28th proceedings
90-04		3-2	Guidelines for materials and processing specification preparation (Materials and Processing) - merged into new item 94-02
90-05	T	2-1.4	Braiding orientation codes (Braiding)
90-09		none	DOD/NASA hardware data collection (Guidelines) - withdrawn due to no action or current interest
90-11			Rule of thumb design/analysis guide (Guidelines) - continued, sections under review in the 28th proceedings, additional work underway
90-12	R	1-8.2.1	Minimum sample size recommendations for Basis values (Statistics) - closed based on sections approved
90-15		none	Real-world statistics simulation (Data Review/Guidelines/Statistics) - withdrawn as redundant
91-05			Between panel variability (Statistics) - continued
91-06		1-8	Curvilinear regression with random effects (Statistics) - continued
91-07		1-2	Engineering perspective on regression (Guidelines) - continued
91-08		1-2	Lamina-laminate material characterization (Guidelines) - continued
91-09	T	2-1.4	Weave notation (Materials & Processes) - continued
91-11			Braiding taxonomy (Braiding) - closed
91-12			Glass transition temperature (Testing) - continued, draft under review
91-13			Case study for alternate material supplier problem (Statistics) - tabled
91-14			Pairing data sets: alternative to the reduced ratio method (Statistics) - withdrawn in favor of regression method
91-15			Examples of statistical applications to real world scenarios (Statistics) - continued, action planned by task group prior to next meeting

ITEM	*	SECTION	TOPIC
91-16	R		Wet winding (Filament Winding) - withdrawn due to no action or current interest
91-18	R		Incoming/Receiving mechanical property tests (Guidelines) - continued
91-20			Stress-strain curves of adhesives (Guidelines) - transferred to Structural Joints, merged into 93-02, and closed
91-21			Establish guidelines for qualification of composite materials (Materials & Processes/Guidelines) - Guidelines interest transferred to Materials & Processes
91-22	R		Fastener-in-composite qualification tests (Structural Joints) - closed based on sections under review in 28th proceedings
91-23			Rules of thumb for bolted joints (Structural Joints/Guidelines) - Renamed Rules of thumb for bolted and bonded joints; continued
91-24			Cross-reinforced testing (Testing) - Withdrawn as a redundant item
91-25			Multi-axial testing (Guidelines/Thick Section Composites) - Guidelines interest transferred to Testing
92-01	R	1-6.6	Update of Volume 1, Section 6.6 (Testing) - continued
92-02		1,2,3	Overall review of the handbook (Guidelines) - continued
92-03		1-6.8	Braiding Test Methods (Braiding) - continued
92-05	R	3-2.5	Fabrication (Materials & Processes) - closed based on sections under review in 28th proceedings
93-01		3-5.2	Design and Analysis of Mechanically Fastened Joints (Structural Joints) - continued
93-02		1-7.3	Bonded Joint Characterization (Structural Joints) - continued, outline developed and beginning to draft and review sections
93-03			Hot/Wet Design Issues (Guidelines) - withdrawn as a redundant item
93-04		1-2.2/6	Revision of Sample Conditioning (Guidelines/Testing) - Combined with item 93-05, renamed Revision of specimen conditioning, draft anticipated by next meeting
93-05			"Dry" Conditioning (Guidelines) - merged with 93-04
93-06			Fiber architecture, material forms, & manufacturing processes (Materials & Processing/Guidelines) - withdrawn as still a research topic
93-07			User's guide (Guidelines) - continued
93-08		1-6.6.3	Offset Shear Strength (Testing) - continued
93-09		1-8.1.4	Data Normalization (Data Review) - continued
93-10			A-basis Sample Size (Guidelines) - withdrawn as redundant
93-11		3-4.4	Failure Criteria Revision (Guidelines) - continued, sections under review in these proceedings
93-12		1-6.7	Filament Winding Tests Revision (Filament Winding) - Testing interest added
93-13			Impact Damage (Guidelines) - Testing interest transferred to Guidelines
93-14		1-5	Chapter 5 Editorial Revision (Testing)
93-15	R	1-6	Mechanical Characterization of High Temperature Composites (Guidelines) - continued; sections under review in these proceedings
93-16		1-8	Analysis of High Temperature Composites (Guidelines) - withdrawn

ITEM *	SECTION	TOPIC
93-17	1-2	Test Matrix for High Temperature Composites (Guidelines) - continued
93-18	3-4.7	Crippling (Guidelines) - sections under review in these proceedings
93-19	3-5.1	Bond surface preparation (Guidelines) - transferred to Structural Joints, merged with 88-18, and closed.
93-20		U.K. handbook review (Harmonization) - continued, presentation planned for next meeting
93-21		Ozone depleting chemicals (Materials & Processes) - text under review in these proceedings
93-22	1-2.2.7	New chapter on Materials and Processes (Materials & Processes) - Section to be included in revised Volume 1, Chapter 2. Renamed Materials & Processes section in Chapter 2
93-23	1-2	Chapter 2 Organizational critique (Guidelines) - continued
94-01	3-4	Inclusion of netting analysis in handbook (Filament Winding) - new agenda item
94-02	3-2	Reorganization of Volume 3, Chapter 2 (Materials & Processes) - new agenda item
94-03	1-7.2/ 8.3/8.4	Mechanically Fastened Joints Data Requirements (Structural Joints)New agenda item. Guidelines for reporting of tests of Section 7.2. Textual changes in the affected sections plus new tables and figures. Completion in 1994.
94-04	3-7.4	Physical property analysis required for thick-section composites 3-D analysis (Thick-Section Composites) - new agenda item
94-05	3-7.5	Process analysis methods (Thick-Section Composites) - new agenda item
94-06	3-7.8	Thick laminate demonstration problems (Thick-Section Composites) - new agenda item
94-07	1-2	Revisiting MOL (Testing/Guidelines) - new agenda item
94-08	1-2/8	Regression analysis and data pooling (Statistics/Guidelines) - new agenda item
94-09	1-6.7	Update of Table 6.7 (Filament Winding) - new agenda item

* Agenda item status: R submitted for review by the Coordination Group; T tabled

4. COORDINATION GROUP REVIEW

The following information is under review by the Coordination Group. Comments on this material should be directed to the MIL-HDBK-17 Secretariat, Materials Sciences, Corporation, 500 Office Center Drive, Suite 250, Fort Washington, PA, 19038. If no negative comments are received by 15 July 1994, this material will be considered as approved. Please note that references are included here with each section; in the handbook, they are included at the end of each chapter.

The sections included in the review are:

Volume 1

1.4.1	Toxicity, Health Hazards, and Safety
1.7	Definitions - new and revised definitions
6.6.1	General [Lamina, Laminate, and Fabric Mechnical Property Tests] - revision
8.4.2	Organization of data in handbook - revision

Volume 3

2.2.1.6	Polyimidies - new
2.2.2.2	Amorphous Thermoplastics - new material to be appended
4.4	Laminate Strength and Failure - revision
4.7.2	Compression postbuckling and cripplijng - replaces Section 4.7.1.8
Chapter 7	Revised outline

Volume 1

1.4.1 Toxicity, Health Hazards, and Safety. Certain processing and test methods discussed in MIL-HDBK-17 may involve hazardous materials, operations or equipment. These methods may not address safety problems associated with their use. It is the responsibility of the user of these methods to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use. The user is referred to the Advanced Composite Materials U. S. Army Interim Health and Safety Guidance for a discussion of the health and safety issues involved in the processing and use of composite materials. This document is generated by the U. S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD. Various composites user groups may also provide guidance on health and safety issues pertinent to composite materials. Restrictions on the use of ozone depleting chemicals are detailed in the Clean Air Act of 1991.

The following definitions are recommended for addition to the current list of Definitions.

Axis of Braiding: The direction in which the braided form progresses.

Bobbin: A cylinder or slightly tapered barrel, with or without flanges, for holding tows, rovings, or yarns.

Braid: A system of three or more yarns which are interwoven in such a way that no two yarns are twisted around each other.

Braid Angle: The acute angle measured from the axis of braiding.

Braid, Biaxial: Braided fabric with two-yarn systems, one running in the $+\theta$ direction, the other in the $-\theta$ direction as measured from the axis of braiding.

Braid Count: The number of braiding yarn crossings per inch measured along the axis of a braided fabric.

Braid, Diamond: Braided fabric with an over one, under one weave pattern, (1 x 1).

Braid, Flat: A narrow bias woven tape wherein each yarn is continuous and is intertwined with every other yarn in the system without being intertwined with itself.

Braid, Hercules: A braided fabric with an over three, under three weave pattern, (3 x 3).

Braid, Jacquard: A braided design made with the aid of a jacquard machine, which is a shedding mechanism by means of which a large number of ends may be controlled independently and complicated patterns produced.

Braid, Regular: A braided fabric with an over two, under two weave pattern (2 x 2).

Braid, Square: A braided pattern in which the yarns are formed into a square pattern.

Braid, Two-Dimensional: Braided fabric with no braiding yarns in the through thickness direction.

Braid, Three-Dimensional: Braided fabric with one or more braiding yarns in the through thickness direction.

Braid, Triaxial: A biaxial braided fabric with laid in yarns running in the axis of braiding.

Capstan: A friction type take-up device which moves braided fabric away from the fell. The speed of which determines the braid angle.

Carrier: A mechanism for carrying a package of yarn through the braid weaving motion. A typical carrier consists of a bobbin spindle, a track follower, and a tensioning device.

Coverage: The measure of the fraction of surface area covered by the braid.

Creel: A framework arranged to hold tows, rovings, or yarns so that many ends can be withdrawn smoothly and evenly without tangling.

Crimp: The undulations induced into a braided fabric via the braiding process.

Crimp Angle: The maximum acute angle of a single braided yarn's direction measured from the average axis of tow.

Crimp Exchange: The process by which a system of braided yarns reaches equilibrium when put under tension or compression.

Fell: The point of braid formation, which is defined as the point at which the yarns in a braid system cease movement relative to each other.

Former Plate: A die attached to a braiding machine which helps to locate the fell.

Jammed State: The state of a braided fabric under tension or compression where the deformation of the fabric is dominated by the deformation properties of the yarn.

Knitting: A method of constructing fabric by interlocking series of loops of one or more yarns.

Laid-In Yarns: A system of longitudinal yarns in a triaxial braid which are inserted between the bias yarns.

Parallel Wound: A term used to describe yarn or other material wound into a flanged spool.

Plied Yarn: A yarn formed by twisting together two or more single yarns in one operation.

Sizing: A generic term for compounds which are applied to yarns to bind the fiber together and stiffen the yarn to provide abrasion-resistance during weaving. Starch, gelatin, oil, wax, and man-made polymers such as polyvinyl alcohol, polystyrene, polyacrylic acid, and polyacetatates are employed.

Sleeving: A common name for tubular braided fabric.

Spindle: A slender upright rotation rod on a spinning frame, roving frame, twister or similar machine.

Twist multiplier: The ratio of turns per inch to the square root of the cotton count.

Unit Cell: The term applied to the path of a yarn in a braided fabric representing a unit cell of a repeating geometric pattern. The smallest element representative of the braided structure.

The following modifications to existing definitions are recommended.

Old: **Fiber:** A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament of finite length.

New: **Fiber:** A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament of finite length. A unit of matter, either natural or manmade, which forms the basic element of fabrics and other textile structures.

Old: **Fill:** Yarn oriented at right angles to the warp in a woven fabric.

New: **Fill (Filling):** In a woven fabric, the yarn running from selvage to selvage at right angles to the warp.

Old: **Mandrel:** A form fixture or male mold used for the base in the production of a part by lay-up or filament winding.

New: **Mandrel:** A form fixture or male mold used for the base in the production of a part by lay-up, filament winding or braiding.

Old: **Modulus, initial:** The slope of the initial straight portion of a stress-strain or load-elongation curve.

New: **Modulus, initial:** The slope of the initial straight portion of a stress-strain curve.

Old: **Pick Count:** The number of filling yarns per inch of woven fabric.

New: **Pick Count:** The number of filling yarns per inch or per centimeter of woven fabric.

Old: **Roving:** A number of strands, tows, or ends collected into a parallel bundle with little or no twist.

New: **Roving:** A number of strands, tows, or ends collected into a parallel bundle with little or no twist. In spun yarn production, an intermediate state between sliver and yarn.

Old: **Selvedge:** The woven edge portion of a fabric parallel to the warp.

New: **Selvage or Selvedge:** The woven edge portion of a fabric parallel to the warp.

Old: **Twist:** The number of turns about its axis per unit of length in a yarn or other textile strand. It may be expressed as turns per inch (tpi).

New: **Twist:** The number of turns about its axis per unit of length in a yarn or other textile strand. It may be expressed as turns per inch (tpi) or turns per centimeter (tpcm).

The deletion of the following definition is recommended:

Yield Point: The first stress in a material at which an increase in strain occurs without a corresponding increase in stress. (The stress is less than the maximum attainable.) It should be noted that only materials that exhibit the unique phenomenon of yielding have a "yield point".

6.6.1 General. Section 6.6 discusses test methods for determining mechanical properties of laminated composites. The purpose of this section is to provide brief commentaries on the most commonly used methods, to alert the reader to the limitations of the various methods, and to encourage uniformity in the use of standard test methods with the ultimate goal of combinability of experimental data obtained from multiple sources. The reader is referred to Chapter 8 for statistical data analysis requirements for reporting of data to MIL-HDBK-17.

The section reflects the current dynamic state of test methods development for composite materials. Many of the methods were originally developed for testing of reinforced plastics, and modifications have been (or are being) made for applicability to advanced composites. In recent years there has been a tendency for users to unilaterally modify existing standards without a formal standardization process, leading to uncontrolled test results. In general, these modified standards are not discussed in Section 6.6 except where a specific modification is in common use, and where discussion of the technique is deemed constructive. The test methods included are representative of procedures used in the composite materials industry, and were selected after review of standards documents and user material specifications.

It is important to make a distinction between methods that are discussed in Section 6.6, and methods for data submittal to MIL-HDBK-17:

- Test methods used by contractors are agreed upon with customers and/or certifying agencies. Section 6.6 reviews many methods in order to provide the reader with awareness of the broad range of procedures in common use. Some of these have been formally standardized (ASTM and other standards) and some are "common practice" methods. Some have distinct limitations, and these are indicated as a matter of information. Mention or omission of a particular method does not, of itself, require or restrict usage. Specific methods are included to allow the user to perform tests consistent with industry practice; however, inclusion of these standards should not be considered an endorsement of any standard or organization by MIL-HDBK-17.

- When submitting data to MIL-HDBK-17 for consideration for inclusion in Volume 2 of the Handbook, specific methods must be used. Tables at the end of most subsections of 6.6 indicate which methods are acceptable for such submittals. These methods have been chosen in accordance with the criteria given in section 2.2.6. Readers are encouraged to also use these methods in contract and internal work to promote standardization.

When selecting and using a particular mechanical strength test method, the importance of obtaining the proper failure mode cannot be overemphasized. While universal definitions of "proper" and "valid" have not been established for most types of tests, further analysis must be employed when unexpected or questionable modes are observed or suspected. If the type of failure is different from what is expected from the test, the data may not represent the property being evaluated. Furthermore, if the failure mode varies within a group of specimens, statistical analysis of the resulting data will not be meaningful due to the introduction of an additional source of variability not related to the property being tested. Therefore, it is crucial that failure modes be reported, and that data be disqualified and discarded when analysis has indicated an unacceptable mode.

It should be noted that failure mode analysis is not necessarily limited to physical examination of the failed test specimens. Other evidence might be obtained from review of additional factors such as:

1. Bending curves from back-to-back strain gage data

2. A check of test machine and/or test fixture alignment

3. A review of the exact procedure used to install and properly align the specimens in the test fixture

4. A check for possible damage to, or malfunction of, the test fixture

ASTM has begun to incorporate failure mode examples and codes into its standard test methods. For example, the 1993 revision of ASTM D3039 (*Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*) depicts nine types of failures of the specimen, and defines a three-character coding system that describes various failures. The first letter of the code identifies the type of failure (angled, grip, delamination, etc.), the second indicates the area of the failure (gage, at grip, etc.), and the third denotes the failure location (top, bottom, middle, etc.). In the particular case of tensile testing, a failure of the tab or tab adhesive would be an unacceptable mode since the ultimate tensile strength of the laminate was not measured.

Rather than duplicate failure mode examples within the subsections of section 6.6, the reader is advised to be conscientious regarding the documentation of failure modes, and to refer to examples provided within specific test methods where such examples exist.

bold indicates changes

8.4.2 Organization of data in handbook. The data in Volume 2 is divided into chapters of fiber properties, resin properties, and composite properties organized by fiber and then resin.

8.4.2.1 *Fiber properties.* **(At the time of this revision no fiber property data has been accepted for inclusion in Volume 2, Chapter 2.)** Chapter 2 in Volume 2 **will provide** data for fiber properties. Sections are to be included for different types of fiber, e.g., glass fibers and carbon fibers. In each section, the general characteristics of the type of fiber **will be** given, as well as an index of suppliers, designations, and abbreviations. For each specific fiber, data **will be** organized in the following manner. The X's in the subsection number **will be** determined by the type of fiber and the specific fiber described.

2.X.X.1 Supplier and product data
2.X.X.2 Chemical and physical properties
2.X.X.2.1 Typical range of chemical constituents
2.X.X.2.2 Expected bound in physical properties
2.X.X.3 **Electrical properties**
2.X.X.4 Thermal-mechanical properties
2.X.X.4.1 Stress-strain curves
2.X.X.4.2 Environmental effects

8.4.2.2 *Matrix properties.* **(At the time of this revision no matrix property data has been accepted for inclusion in Volume 2, Chapter 3.)** Matrix or resin properties **will be** included in Chapter 3 which **will be** divided into sections according to the type of resin. For example, Section 3.2 **will give** data for epoxies and Section 3.3 **will provide** data for polyester resins. The subsections for each resin **will be** the same as those in Chapter 2 given above.

8.4.2.3 *Composite properties.* The remaining chapters of Volume 2 **will provide** data for prepreg, lamina, laminate, and joint properties. There **will be** individual chapters for each family of composites based on fiber type. For example, Chapter 4 describes carbon fiber composites. Within each chapter, there is expected to be an index of suppliers, designations, and abbreviations. Sections **will be** included based on the resin type used with the fiber described in the chapter, e.g., Section 4.3 **will provide** properties for epoxy-carbon composites.

Properties **will be** organized in the following manner for each specific composite:

X.X.X.1 Supplier and product data
X.X.X.2 Prepreg chemical and physical properties
X.X.X.2.1 Physical description
X.X.X.2.2 Resin content
X.X.X.2.3 Fiber content
X.X.X.2.4 Volatiles content
X.X.X.2.5 Moisture content
X.X.X.2.6 Inorganic fillers and additives content
X.X.X.2.7 Areal weight
X.X.X.2.8 Tack and drape
X.X.X.2.9 Resin flow

X.X.X.2.10 Gel time
X.X.X.3 Lamina chemical properties
X.X.X.4 Lamina physical properties
X.X.X.5 Lamina mechanical properties
X.X.X.5.1 Data Summaries
X.X.X.5.2 Typical stress-strain curves
X.X.X.6 Thermal properties
X.X.X.7 Electrical properties
X.X.X.8 Laminate thermal-mechanical properties
X.X.X.8.1 Index of properties by lay-up
X.X.X.8.2 Strength properties
a. Lay-up No. 1
b. Lay-up No.2
X.X.X.8.3 Thermal properties
X.X.X.8.4 Electrical properties
X.X.X.9 Joint thermal-mechanical properties
X.X.X.9.1 Index of properties by joint and composite system
X.X.X.9.2 Bearing strength
a. System No. 1
b. System No.2

2.2.1.6 *Polyimides.* The polyimide resin family comprises a diverse number of polymers all of which contain an aromatic heterocyclic ring structure. The bismaleimides discussed in 2.2.1.5 are a subset of this family. Other polyimides are synthesized from a variety of cyclic anhydrides or their diacid derivatives through reaction with a diamine. This reaction forms a polyamic acid which then undergoes condensation by the removal of water and/or alcohol.

Polyimide matrix composites excel in high temperature environments where their thermal resistance, oxidative stability, low coefficient of thermal expansion and solvent resistance benefit the design. Their primary uses are circuit boards and hot engine and aerospace structures.

A polyimide may be either a thermoset resin or a thermoplastic. The thermoplastic varieties are discussed in 2.2.2.2. Thermosetting polyimides characteristically have crosslinkable end caps and/or a rigid polymer backbone. A few thermoplastic polyimides can become thermoset polymers if a sufficiently high postcure temperature is employed during part processing. Alternately, partially cured thermoset polyimides containing residual plasticizing solvents can exhibit thermoplastic behavior. Thus, it is difficult to state with certainty that a particular polyimide is indeed a thermoset or thermoplastic. Polyimides, therefore, represent a transition between these two polymer classifications.

Polyimide properties, such as toughness and thermal resistance, are influenced by the degree of crosslinking and chain extension. Molecular weight and crosslink density are determined by the specific end cap group and by the stoichiometry of the anhydride:amine mixture which produces the polyamic acid by stepwise chain growth, after which the polyamic acid is recyclized by continued thermal cure to form the final polymer structure. The choice of solvent employed in the resin formulation has a significant impact on crosslinking and chain extension. Solvents such as N-methyl 2-pyrrolidone (NMP), promote chain extension by increasing resin flow, chain mobility and molecular weight prior to formation of a substantial crosslink network. From a practical standpoint, these solvents are beneficial to polymerization, but they are detrimental to part manufacture because of their tendency to cause ply delaminations.

Most polyimide resin monomers are powders. Some bismaleimides are an exception. As a result, solvents are also added to the resin to enable impregnation of unidirectional fiber and woven fabrics. Commonly, a 50:50 by weight mixture is used for fabrics, and a 90:10 by weight high solids mixture is used to produce a film for unidirectional fiber and low areal weight fabric prepregs. Solvents are further used to control prepreg handling qualities, such as tack and drape. Most of the solvents are removed in a drying process during impregnation, but total prepreg volatiles contents typically range between 2 and 8% by weight. This includes all volatiles, including those produced by the condensation cure reactions.

Polyimides require high cure temperatures, usually in excess of 550°F (~90°C). Consequently, normal epoxy composite consumable materials are not usable, and steel tooling becomes a necessity. Polyimide bagging and release films, such as Kapton and Upilex, replace the lower cost nylon bagging and polytetrafluoroethylene (PTFE) release films common to

epoxy composite processing. Fiberglass fabrics must be used for bleeder and breather materials instead of polyester mat materials.

Continuation of 2.2.2.2

One important class of amorphous thermoplastic matrices is the condensation cure polyimides. Examples include polyamideimides, such as Torlon, and polyimides having more flexible backbones, such as AvimidR K3B, NR 150B2 and the LaRC polymers developed by NASA. As stated in 2.2.1.6, polyimides represent a transition between thermoset and thermoplastic polymers. Thus, these thermoplastics also have many characteristics typical of epoxy and phenolic thermoset polymers (e.g., excellent solvent resistance and high maximum operating temperature limits).

Due to negligible crosslink density, these polymers impart some toughness to composite laminates and permit limited flow during processing, although this flow is more like the high creep rates exhibited by superplastic metals. Unlike other thermoplastics, these polymers do not produce liquid flows, even under high consolidation pressures. Typical processing conditions for the condensation cure thermoplastics are 550°F (290°C) and greater temperatures with consolidation pressures starting at 200psig (1.4 MPa).

Many of these thermoplastic polymers have been developed with the intent to rapidly stamp or compression mold structural composites parts at low cost. However, this potential has yet to be realized because of low production volumes, high capital equipment and tooling costs as well as excessive fiber distortion in the formed part. The most successful structural applications of these polymers have utilized autoclave processing to reduce tooling costs and fiber distortion. Other polymers in this class have been developed for use in circuit boards because of their low dielectric constant, low moisture absorption and low coefficient of thermal expansion. In these applications, compression molding had been found to be advantageous and cost effective.

Compared to other thermoplastic polymers, the condensation cure thermoplastics have not found a wide variety of applications. Their processability is very similar to the thermosetting polyimides, and this has been a limiting factor. Volatiles are produced by the condensation reaction, and they cause laminate porosity unless consolidation pressures are high enough to suppress void nucleation and growth. Costly high temperature tooling and consumable materials (e.g., vacuum bags and release films) are also required for part processing. While the toughness and processability of many of these condensation cured thermoplastic polyimides are slightly better than those of competing thermosetting polyimides, their maximum operation temperature limit is somewhat lower. For the present, these thermoplastic polymers are limited to special niche markets which take advantage of their unique performance capabilities.

2.2.2.3 Delete Section

MIL-HDBK-17 Failure Material
Draft--5/10/94

Comments on this draft

There are still six items which are being discussed with regard to final wording strike through and underline. The at the time of this draft. These are indicated by strike through indicates text which is being considered for deletion while underline indicates text which is being considered for inclusion. If both are shown, there the two options of text are being considered.

Please comment on these six items in addition to other general items.

4.4 LAMINATE STRENGTH AND FAILURE. Methods of stress analysis of laminates subjected to mechanical loads, temperature changes, and moisture absorption were presented in Section 4.3.5. The results of such a stress analysis can be used to assess the strength of a laminate. As a result of the complexity of the structure of a composite laminate, several modes of failure are possible, and it is desirable for the failure mode as well as the failure stress or strain to be predicted. The analytical problem is to define the failure surface for the laminate in either stress or strain space.

Laminate failure may be calculated by applying stress or strain limits at the laminate level or, alternatively, at the ply level. Ply level stresses or strains are the more frequently used approach to laminate strength. The average stresses in a given ply may be used to calculate either an onset of damage, which is frequently called "first ply failure", or a critical failure which is regarded as ultimate strength. In the former case, subsequent damages leading to laminate failure are then calculated. This calculation of subsequent damage is sometimes performed using the "sequential ply failure" methodology, and sometimes performed using "netting" analysis. These approaches are discussed subsequently. Four factors should be considered in assessing the validity of using ply level stresses for failure calculation. The first is the question of which tests (or analyses) should be used to define the ply strength values. In particular, it must be recognized that a crack parallel to the fibers may result in failure of a transverse tensile test specimen of a unidirectional composite, while the same crack may have an insignificant effect in a laminate test. The second factor is the assumption that local failures within a ply are contained within the ply and are determined solely by the stress/strain state in that ply. There is evidence that the former assumption is not valid under fatigue loading, during which a crack within one ply may well propagate into adjacent plies. In this case, the ply-by-ply model may not be the best analytical approach. Furthermore, matrix cracking within one ply is not determined uniquely by the stresses and strains within that ply but is influenced by the orientation of adjacent layers as well as by the ply thickness. **(Reference: D.L. Flaggs and M.H. Kural, "Experimental Determination of the In Situ Transverse Lamina Strength in Graphite/Epoxy Laminates", Journal of Composite Materials, Vol. 16, March, 1982, pp. 103-115.)** The third factor is the existence of residual thermal stresses, usually of unknown magnitude, resulting from the fabrication process. The fourth factor is that it does not cover the possibility of delaminations which can occur, particularly at free edges. Thus, the analysis is limited to in-plane failures.

4.4.1 Sequential ply failure approach.

4.4.1.1 *Initial ply failure.* To predict the onset of damage, consider stresses remote from the edges in a laminate which is loaded by in-plane forces and/or bending moments. If there is no external bending, if the membrane forces are constant along the edges, and if the laminate is balanced and symmetric, the stresses in the ith layers are constant and planar. With reference to the material axes of the laminae, fiber direction x_1 and transverse direction x_2, the stresses in the ith ply are written σ^i_{11}, σ^i_{22}, and σ^i_{12}. Failure is assumed to occur when the selected semi-empirical failure criteria involving these calculated stresses or the associated strains are satisfied. Numerous criteria have been proposed for calculation of onset of damage. These may be grouped into two broad categories - mode-based and purely empirical. Mode - based criteria treat each identifiable physical failure mode, such as fiber-direction tensile failure and matrix-dominated transverse failure, separately. A purely empirical criterion generally consists of a polynomial combination of the three stress or strain components in a ply. Such criteria attempt to combine the effects of several different failure mechanisms into one function and may, therefore, be less representative than physically based criteria. All criteria rely on test data at the ply level to set parameters and are therefore at least partially empirical in nature.

The selection of appropriate criteria can be a controversial issue and the validity of any criterion is best determined by comparison with test data. As a consequence, different criteria may be best for different materials. Two mode-based failure criteria are presented here as examples: the maximum strain criteria and the failure criteria proposed by Hashin. It is important, however, for the engineer to consider the material, the application, and the test data in choosing and utilizing a failure criterion.

The maximum strain criteria may be written as

$$\begin{aligned} \epsilon^{cu}_{11} \le \epsilon^{i}_{11} \le \epsilon^{tu}_{11} \\ \epsilon^{cu}_{22} \le \epsilon^{i}_{22} \le \epsilon^{tu}_{22} \\ | \epsilon^{i}_{12} | \le \epsilon^{su}_{12} \end{aligned} \qquad 4.4.1.1(a)$$

For given loading conditions, the strains in each ply are compared to these criteria. Whichever strain reaches its limiting value first indicates the failure mode and first ply to fail for those loading conditions. The limiting strains, ϵ^{tu}_{11}, ϵ^{cu}_{11}, etc., are the specified maximum strains to be permitted in any ply. Generally, these quantities are specified as some statistical measure of experimental data obtained by uniaxial loading of a unidirectional laminate. For example, in the case of axial strain, ϵ_{11}, a B-basis strain allowable from unidirectional tests can be used. Other limits may also be imposed. For example, in the case of shear strain, something equivalent to a "yield" strain may be used in place of the ultimate shear strain.

The failure criteria proposed by Hashin (Reference: Z. Hashin, "Failure Criteria for Unidirectional Fiber Composites", Journal of Applied Mechanics, Vol. 47, June, 1980, pp. 329-334) may be written as:

Fiber modes

Tensile

$$\left(\frac{\sigma_{11}}{F_1^{tu}}\right)^2 + \left(\frac{\sigma_{12}}{F_{12}^{su}}\right)^2 = 1 \qquad 4.2.4(f)$$

Compressive

$$\left(\frac{\sigma_{11}}{F_1^{cu}}\right)^2 = 1 \qquad 4.2.4(g)$$

Matrix modes

Tensile

$$\left(\frac{\sigma_{22}}{F_2^{tu}}\right)^2 + \left(\frac{\sigma_{12}}{F_{12}^{su}}\right)^2 = 1 \qquad 4.2.4(h)$$

Compressive

$$\left(\frac{\sigma_{22}}{2F_{23}^{su}}\right)^2 + \left[\left(\frac{F_2^{cu}}{2F_{23}^{su}}\right)^2 - 1\right]\left(\frac{\sigma_{22}}{F_2^{cu}}\right) + \left(\frac{\sigma_{12}}{F_{12}^{su}}\right)^2 = 1 \qquad 4.2.4(i)$$

It should be noted that some users of these criteria add a shear term to equation 4.2.4(g) to reflect the case in which shear mode instability contributes to the compressive failure mechanism (Reference: Fiber Composite Analysis and Design, Federal Aviation Administration, DOT/FAA/CT-85/6). In that case, equation 4.2.4(g) is replaced by:

$$\left(\frac{\sigma_{11}}{F_1^{cu}}\right)^2 + \left(\frac{\sigma_{12}}{F_{12}^{su}}\right)^2 = 1 \qquad 4.4.1.1(b)$$

The limiting stresses in the criteria, F_1^{cu}, F_{12}^{su}, etc., are the specified maximum stresses to be permitted in any ply. As with the case of strains, statistical data from unidirectional tests are generally used to define these quantities. However, as an example of the care required, it should be noted that the stress which produces failure of a 90° coupon in tension is not necessarily a critical stress level for a ply in a multidirectional laminate. One may wish to use, instead, the stress level at which crack density in a ply reduces the effective stiffness by a specified amount. Such a stress level could be determined by either a fracture mechanics analysis or testing of a crossply laminate. (See, for example, Flaggs and Kural, 1982)

In an onset of damage approach, the selected failure criteria are used for each layer of the laminate. The layer for which the criteria are satisfied for the lowest external load set will

define the loading which produces the initial laminate damage. The layer which fails and the nature of the failure (i.e., fiber failure or cracking along the fibers) are identified. This is generally called first-ply failure. When the first ply failure is the result of fiber breakage, the resulting ply crack will introduce stress concentrations into the adjacent plies. In this case, it is reasonable to consider that first ply failure is equivalent to laminate failure. A different criterion exists when the first ply failure results from matrix cracking and/or fiber/matrix interface separations. Here it is reasonable to consider that the load-carrying capacity of the ply will be changed significantly when there is a substantial amount of matrix mode damage. Treatment of this case is discussed in the following section.

Additional concerns to be addressed in considering the initial failure or onset of damage include bending, edge stresses, and residual thermal stresses. Bending occurs when there are external bending and/or twisting moments or when the laminate is not symmetric. In these cases the stresses σ^{l}_{11}, σ^{l}_{22}, and σ^{l}_{12} in a layer are symmetric in x_3. Consequently, the stresses assume their maximum and minimum values at the layer interfaces. The failure criteria must be examined at these locations for each layer. Different approaches utilize the maximum value or the average value in such cases.

The evaluation of onset of failure as a result of the edge stresses is much more complicated as a result of the sharp gradients (indicated by analytical singularities) in these stresses. Numerical methods cannot uncover the nature of such stress singularity, but there are analytical treatments (e.g. Reference 4.4.1) which can. The implication of such edge stress fields for failure of the laminate is difficult to assess. This situation is reminiscent of fracture mechanics in the sense that stresses at a crack tip are theoretically infinite. Fracture mechanics copes with this difficulty with a criterion for crack propagation based on the amount of energy required to open a crack, or equivalently, the value of the stress intensity factor. Similar considerations may apply for laminate edge singularities. This situation in composite materials is more complicated since a crack initiating at the edge will propagate between anisotropic layers. It appears, therefore, that at the present time the problem of edge failure must be relegated to experimentation, or approximate analysis.

In the calculation of first-ply failure, consideration must also be given to residual thermal stresses. The rationale for including residual thermal stresses in the analysis is obvious. The stresses exist after processing. Therefore, they can be expected to influence the occurrence of first-ply failure. However, matrix materials exhibit viscoelastic, or time-dependent, effects, and it may be that the magnitude of the residual stresses will be reduced through a process of stress relaxation. Additionally, the processing stresses may be reduced through the formation of transverse matrix microcracks. The question of whether to include residual stresses in the analysis is complicated by difficulties in measuring these stresses in a laminate and by difficulties in observing first-ply failure during a laminate test. It is common practice to neglect the residual thermal stresses in the calculation of ply failure. Data to support this approach do not appear to be available. However, at the present time, damage tolerance requirements limit allowable strain levels in polymeric matrix laminates to 3000 to 4000 μin/in. This criterion becomes the dominant design restriction and obviates, temporarily, the need to resolve the effects of residual thermal stresses.

4.4.1.2 *Subsequent failures.* Often laminates have substantial strength remaining after the first ply has experienced a failure, particularly if that first failure is a matrix-dominated

failure. A conservative approach for analyzing subsequent failure is to assume that the contribution of that first failed ply is reduced to zero. If failure occurs in the fiber-dominated mode, this may be regarded, as discussed earlier, as ultimate laminate failure. If not, then the stiffness in the fiber direction E_L is reduced to zero. If failure occurs in the matrix-dominated mode, the elastic properties E_T and G_L are reduced to zero. The analysis is then repeated until all plies have failed. Generally, the progressive failures of interest are initial and subsequent failures in the matrix mode. In that case, the basic assumptions for netting analysis result where the ultimate load is defined by E_T and G_L vanishing in all laminae. The basic issues involved in modeling post-first-ply behavior are described in Reference 4.4.2. For some materials and/or for some properties, matrix mode failures may not have an important effect. However, for some properties, such as thermal expansion coefficients, ply cracking may have a significant effect.

4.4.2 Fiber failure approach (laminate level failure). In composites laminates~~, as described in the previous section,~~ there are two characteristic stress or strain levels which can be considered in the evaluation of strength. One is the stress or strain state at which a non-catastrophic first-ply failure can occur and the other is the maximum static stress or strain state which the laminate can carry. In those cases where the material exhibits minimal micro-cracking, or where the application is such that effects of micro-cracking need not be considered, a failure criterion based only upon fiber failure may be used. A common practice in the aerospace industry is to use a failure criterion based only upon fiber strain allowables, for which fiber failure in any lamina is considered laminate ultimate failure. Hence, failure is a single event rather than the result of a process.

Perhaps the most common example of this laminate level failure criterion is a modification of the *maximum strain criterion* [see for example....need a reference]. The same assumptions of no external bending, membrane forces constant along the edges, and a balanced and symmetric laminate, are initially used. The basic lamina failure envelope is the same as the conventional maximum-strain envelope for tension- and compression-dominated loads, but introduces truncations in the tension-compression (shear) quadrants as shown in Figure 4.4.2. A critical assumption in this criterion is that the laminate behavior is fiber-dominated meaning that there are fibers in sufficient multiple directions such that strains are limited by the presence of the fibers to inhibit matrix cracking. In many practical applications, this typically translates into having fibers in (at least) each of four directions relative to the primary loads: 0°, 90°, and ±45°. Furthermore, plies are not "clustered" (that is, several plies of the same orientation are not layed together) in order to inhibit matrix macrocracking. With these ~~critical~~ assumptions, the first translation of the maximum strain criterion to the laminate level is a limiting of the strain in the transverse direction, θ_{90}, to the fiber direction limiting strain to reflect the fact that such "well-designed" laminates with fibers in multiple directions restrict strains in any in-plane direction. Alternatively, if there is reason to believe that matrix cracking will be structurally significant, the 90° strain cutoff based on fiber direction strain could be replaced by an empirically established tensile ~~strain~~ limit reflecting a matrix-dominated mode. This limit was originally expressed as a constant strain limit. However, ~~Note that~~ if such a limit is based upon the case of a constant 90° stress in a ply, this would result in a sloped line in the strain plane with the slope related to the Poisson's ratio of the unidirectional lamina:

$$\alpha = \tan^{-1}\left(\nu_{LT}^{lamina}\right) \qquad 4.4.2(a)$$

Such a cutoff is parallel to the uniaxial load line shown in Figure 4.4.2. It should be further noted that possible limitations due to lamina level shear strains are inoperative due to the assumption that the fibers in multiple directions restrict such strains to values below their failure values.

Many users recognize a need to truncate the maximum strain predictions in the tension-compression quadrants. While the particular truncations vary, perhaps the most widely used version is that shown in Figure 4.4.2. These truncations were originally based on data obtained for shear loading of such fiber-dominated laminates. These data lie in the second and fourth quadrants. The 45° cutoffs represent the locus of constant shear strain. These two symmetric truncations are located by finding the intersections of the limiting uniaxial strain lines with the lines representing pure uniaxial stress conditions in fiber directions in 0° and 90° unidirectional plies. At this point, the axial strain now becomes more critical than the shear. The endpoints of the truncations are therefore found by drawing lines through the origin with angles from the relative axes of a which account for the unidirectional ply Poisson's ratio:

$$\alpha = \tan^{-1}\left(\nu_{LT}^{lamina}\right) \qquad 4.4.2(b)$$

thereby yielding the desired pure uniaxial state of stress in the fiber direction. The intersection of these two lines with the greater of the two pure uniaxial stress conditions in the unidirectional plies locates the endpoint of each cutoff. It is always necessary that the cutoff be located by the higher of the uniaxial strengths since, otherwise, the cutoff would undercut

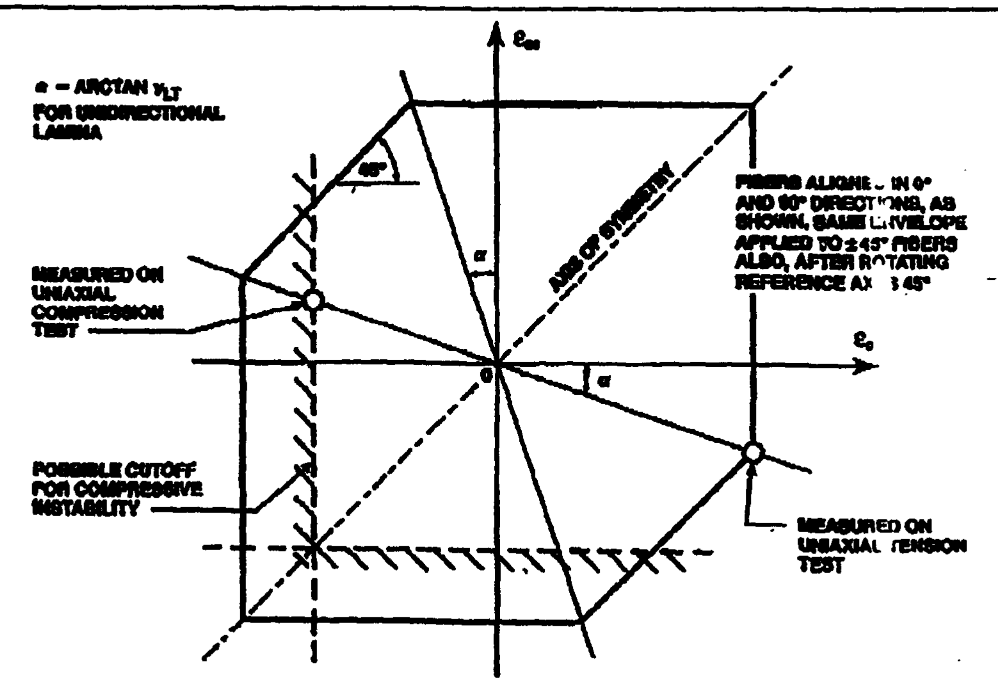


FIGURE 4.4.2 *Illustration of laminate level failure approach.*

the measured uniaxial strain to failure at the other end. This procedure results in the same failure diagram for all fiber-dominated laminates. It should be ~~noted~~ emphasized that this procedure requires the use of the Poisson's ratio of the unidirectional ply even when the laminate contains fabric plies.

This failure model, as represented in Figure 4.4.2, has been developed from experience with fiber-reinforced polymer matrix composites used on subsonic aircraft, particularly with carbon-epoxy materials, for which the lamina n_{TL} is approximately 0. It should not be applied to other composites, such as whisker-reinforced metal-matrix materials. Figure 4.4.2 addresses only fiber-dominated failures because, for the fiber polymer composites used on subsonic aircraft, the microcracking in the matrix has not been found to cause reductions in the static strength of laminates, particularly if the operating strain level has been restricted by the presence of bolt holes or provision for damage tolerance and repairs. However, with the advent of new composite materials, cured at much higher temperature to withstand operation at supersonic speeds, this approach may no longer be appropriate. The residual stresses developed during cool-down after cure will be far higher, because of the greater difference between the cure temperature and the minimum operating temperature.

This set of truncations together at the laminate level with the original maximum strain criterion results in the following operative set of equations applied ~~on a ply by ply basis~~ *at the laminate level* with respect to axes oriented along and normal to each fiber direction in the laminate

$$
\begin{aligned}
& e_{11}^{cu} \le e_{11}^{l} \le e_{11}^{tu} \\
& e_{11}^{cu} \le e_{22}^{l} \le e_{11}^{tu} \qquad \text{4.4.2(c)} \\
& |e_{11}^{l} - e_{22}^{l}| \le \left(1 + \nu_{LT}^{lamina}\right) |e_{11}^{tu} \text{ or } e_{11}^{cu}|^{*}
\end{aligned}
$$

* whichever is greater

However, it is important to note that these equations can only be applied in the context of a fiber-dominated laminate as previously described. It should further be noted that the limits on the transverse strain in each ply, e_{22}^{l}, are set by the fibers in plies transverse to the ply under consideration and thus cannot characterize matrix cracking. This must be carefully taken into account if hybrid laminates are utilized. Furthermore, as previously discussed, if matrix cracking is considered to be structurally significant, a stress or strain cutoff must be added based on empirical observation. In this case, an assessment of the effects of the matrix cracks on subsequent properties of the laminate must be made.

As noted in section 4.4.1, bending occurs when there are external bending and/or twisting moments or when the laminate is not symmetric. In these cases, as with other failure criteria, it is necessary to take into account the fact that the laminate level strains vary through the thickness.

4.4.3 Laminate design. Design charts in the form of "carpet plots" are valuable for selection of the appropriate laminate. Figure 4.4.3 presents a representative carpet plot for

the axial tensile strength of laminates having various proportions of plies oriented at 0°, ±45°, and 90°. Appropriate strength data suitable for preliminary design can be found for various materials in References 4.4.3(a) and (b).

The development of laminate stacking sequence (LSS) optimization routines for strength-critical designs is a difficult task. Such a scheme must account for competing failure mechanisms that depend on material, load type (e.g., tension versus compression), environment (e.g., temperature and moisture content) and history (e.g., fatigue and creep). In addition, the load transfer must be adequately modeled to account for component geometry and edge effects. Even for a simple uniaxial load condition, the relationship between LSS and strength can be complex. Some qualitative rules currently exist for optimizing LSS for strength but they have been developed for a limited number of materials and load cases.

Relationships between LSS and laminate strength depend on several considerations. The initiation and growth of local matrix failures are known to depend on LSS. As these failures occur, internal stress distributions also depend on LSS strength through local stiffness and dimensional stability considerations. For example, delamination divides a base laminate into sublaminates having LSS that are generally unsymmetric. Reduced stiffness due to edge delaminations, causes load redistribution and can decrease the effective tensile strength of laminates. Likewise, local instability of sublaminates also causes load redistribution which can lower the effective compressive strength of laminates. As a result, both laminate and sublaminate LSS affect laminate strength.

Shear stress distributions play a significant role in determining the mechanical behavior and response of multi-directional laminates. As was the case for ply transverse tensile strength, ply shear strength depends on LSS. Laminates with homogeneous LSS have been found to yield higher in-situ ply shear strengths than those with ply orientations clumped in groups (Reference 4.4.3(b)). An inherent flaw density and interlaminar stresses appear to be major factors affecting the distribution of ply shear strengths in a LSS.

As was the case for bending stiffness, bending strength in composite laminates is strongly dependent on LSS. Failure mechanisms characteristic of tension, shear, and compression load conditions may all combine to affect bending strength. Table 4.3.3.2(b) showed that preferential stacking of plies in outer layers of the LSS increased bending stiffness. The bending strength performance of undamaged laminates may show similar trends; however, surface damage due to impact or other in-service phenomena would cause severe degradation to such laminates.

Additional information on laminate stacking sequence effects is found in Section 4.6.5.

4.7.2 Compression postbuckling and crippling. Wide exploitation of advanced composites in stability critical structural designs depends to a large degree on the ability of composites to support loads well beyond the initial buckling level. Unquestionably, the high stiffness-to-weight ratio of composites renders them potentially attractive up to initial buckling. However, since postbuckling design has been established over several decades for certain types of conventional metallic alloy construction, it should be anticipated that composites demonstrate a similar capability. Hence, this section addresses this vitally important issue as it pertains to the design of structural compression members. At this point it is appropriate to state the following definitions:

Postbuckling. The ability of a compression member or stiffened panel to carry loads well in excess of initial buckling load. The "postbuckling range" may be considered to exist between the initial buckling load and some higher load representing failure, e.g., delamination at the free edge of a compression member or the disbonding of a stiffener from the panel in a stiffened panel. For basic elements, comprising a simple structural constituent panel, the upper limit of the postbuckling range is sometimes termed "local crippling" or simply "crippling".

Crippling. Compression crippling is a failure in which the cross section of a stiffener is loaded in compression and becomes distorted in its own plane without translation or rotation of the entire column taking place. Typical deflected shapes seen in crippling tests of angles and channel section stiffeners are shown in Figure 4.7.2(a). Angles or cruciforms loaded in compression are commonly used as crippling specimens for the "one-edge-free" case. Channels or simply supported compression panels are normally used for the "no-edge-free" case, in which the center channel segment is approximately simply supported with "no-edge-free".

The postbuckling behavior of composite plates presented here is derived from the empirical graphite tape data obtained from References 4.7.2(a) through (i). Relatively narrow plates, with simply supported unloaded edges or one-edge-free and fixed loading edges were tested and analyzed. The simply supported unloaded edges were simulated by the use of steel V-blocks mounted on the compression test fixture. Specifically, the plates with both unloaded edges simply supported are defined as "no-edge-free". Plates with one unloaded edge simply supported and the other free are defined as "one-edge-free". A typical no-edge-free test in progress with the specimen in the postbuckling range is shown in Figure 4.7.2(b). In addition, a typical one-edge-free test where crippling of the specimen has occurred is shown in Figure 4.7.2(c). Typical load-displacement curves of no-edge-free and one-edge-free tests are shown in Figures 4.7.2(d) and 4.7.2(e), respectively. The most convenient plot that exemplifies the postbuckling strength of the no-edge-free composite plates is shown in Figure 4.7.2(f). The value for F_{11}^{cu} is the ultimate compressive strength of the particular laminate. A typical failed test specimen is shown in Figure 4.7.2(g). Figure 4.7.2(h) illustrates the postbuckling strengths of one-edge-free plates. Note that all the empirical data presented involved the testing of high strength graphite epoxy tape. Other material systems or other forms of graphite epoxy composites may yield different results.

4.7.2.1 *Analytical models.* It was stated in Section 4.7.1.2 that initial buckling was more accurately determined by including the effects of transverse shear and material nonlinearity as is done in References 4.7.1.3(c) and (d). The postbuckling and crippling loads can be

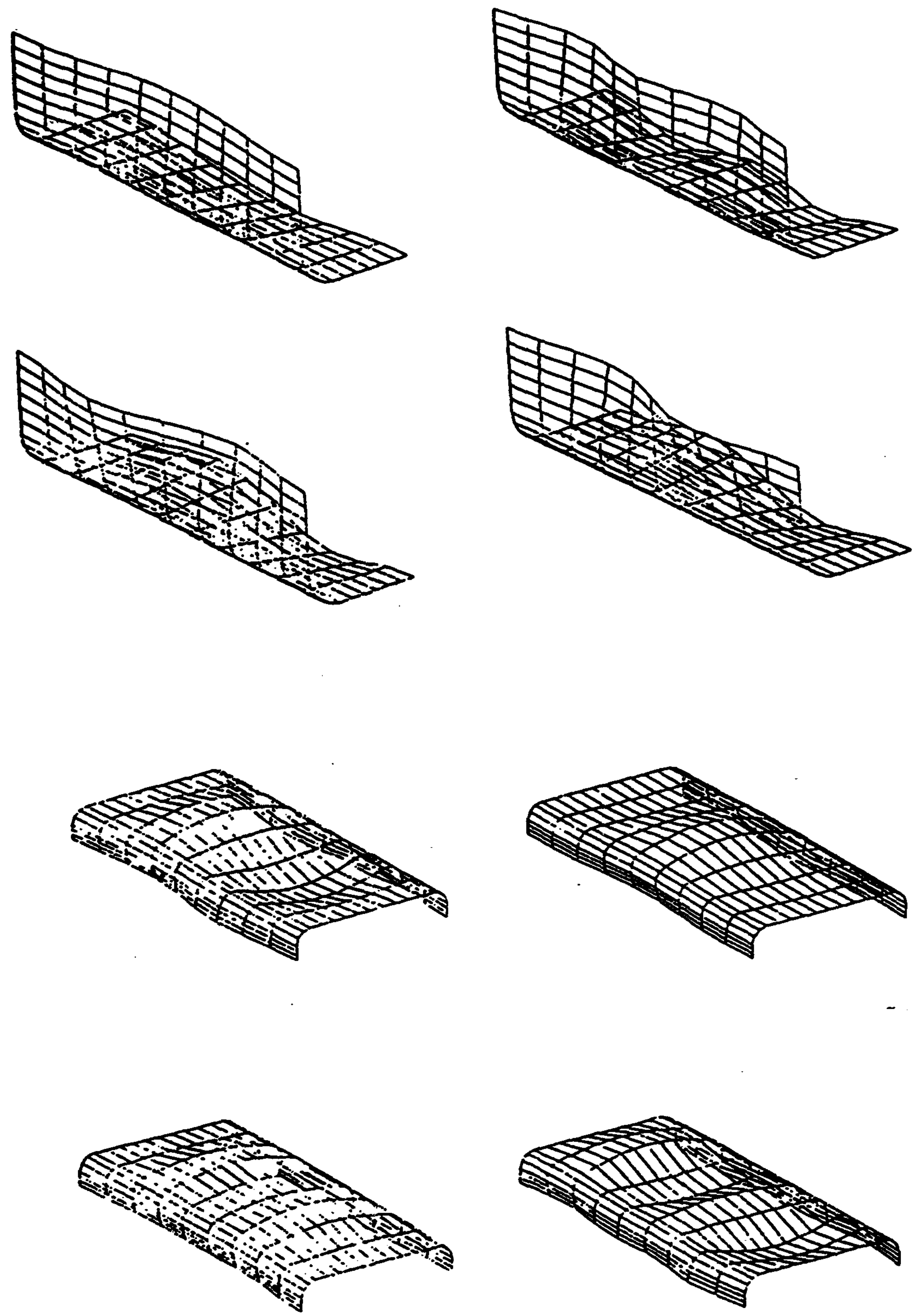


FIGURE 4.7.2(a) *Typical crippling shapes.*

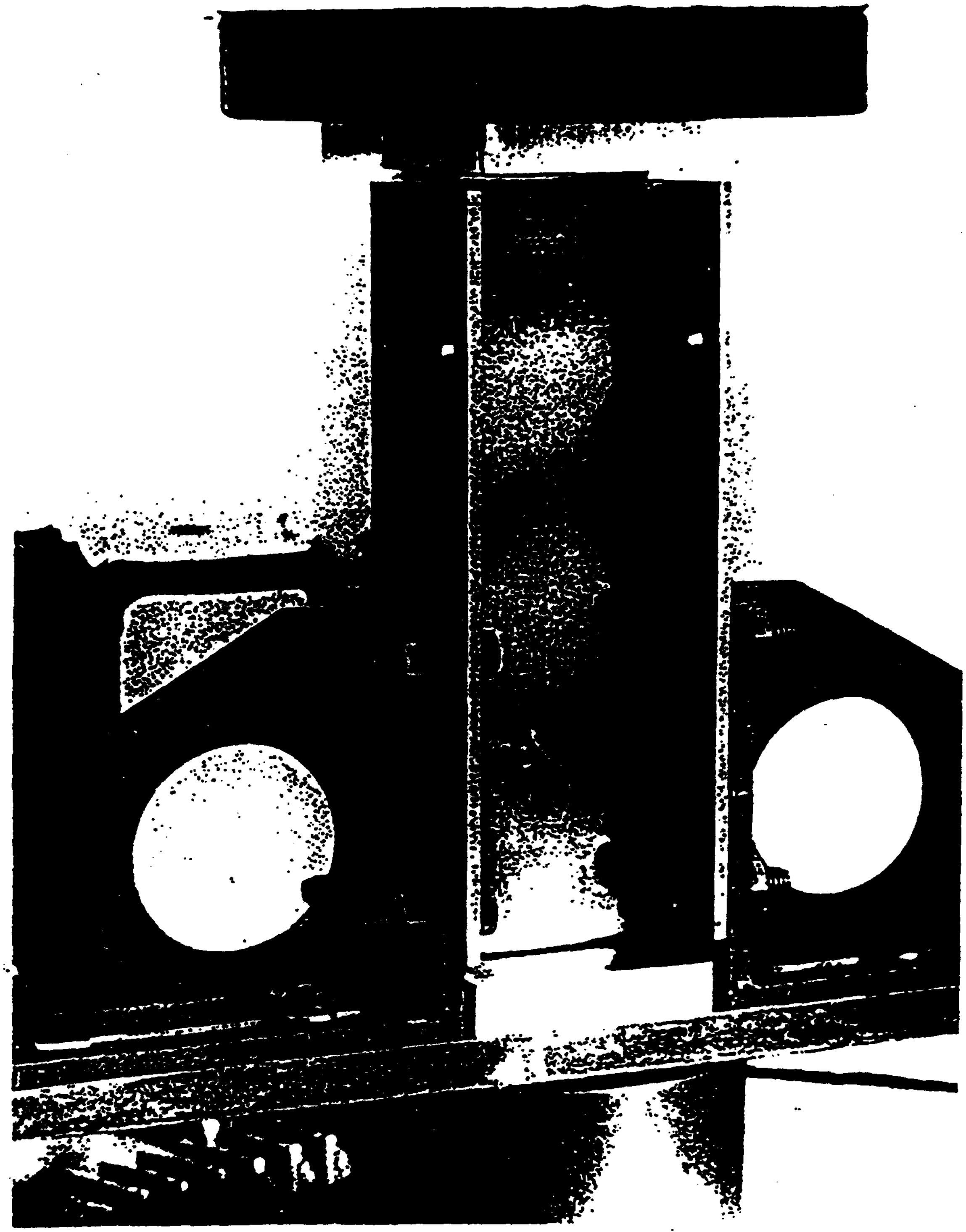


FIGURE 4.7.2(b) *No-edge-free graphite/epoxy test.*

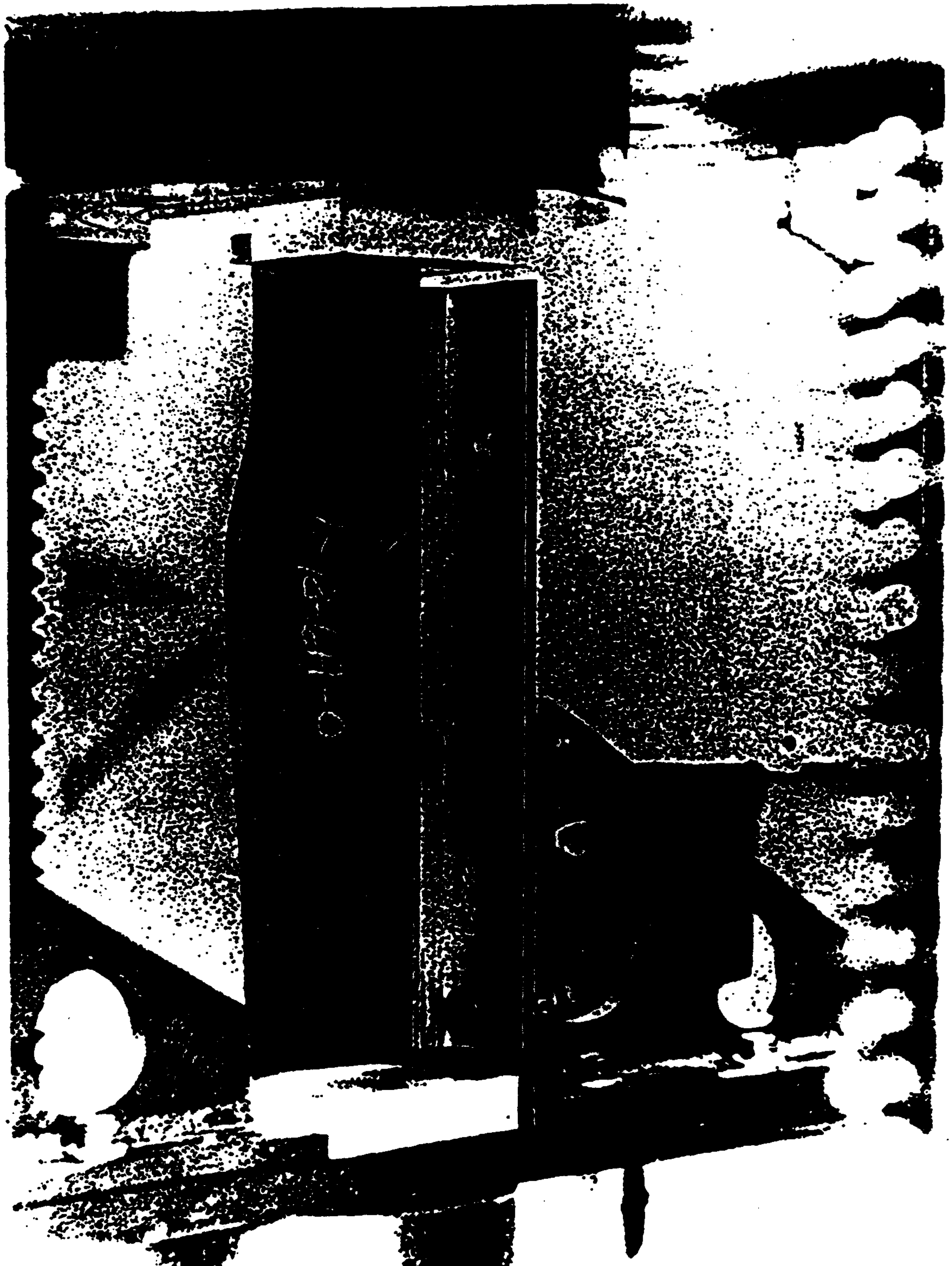


FIGURE 4.7.2(c) *One-edge-free graphite/epoxy postbuckling test at crippling.*

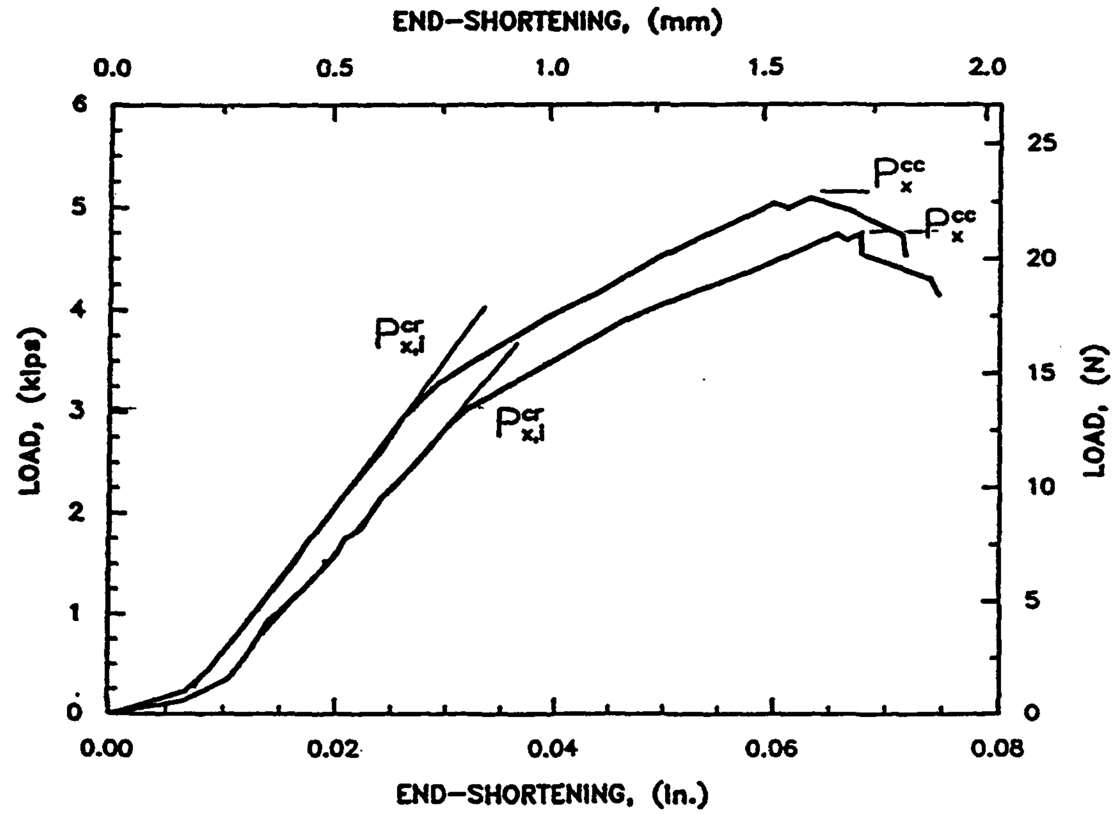


FIGURE 4.7.2(d) *No-edge-free plate. Crippling tests - AS/3501-6 $[\pm 45/90/0_3]_s$ - b/t = 32.*

determined accurately when these effects are included. Some examples of test results vs. the theory of these references are shown in Figures 4.7.2.1(a) and 4.7.2.1(b). Unfortunately, the computer programs available today do not have the features found in these references.

Attempts to predict compression crippling by "conventional" plate buckling programs have not been entirely successful. One example is shown in Figure 4.7.2.1(c), which shows experimental crippling curves and theoretical buckling curves for a quasi-isotropic T300/5208 laminate. (The AS/3501 and T300/5208 graphite/epoxy crippling data was taken from

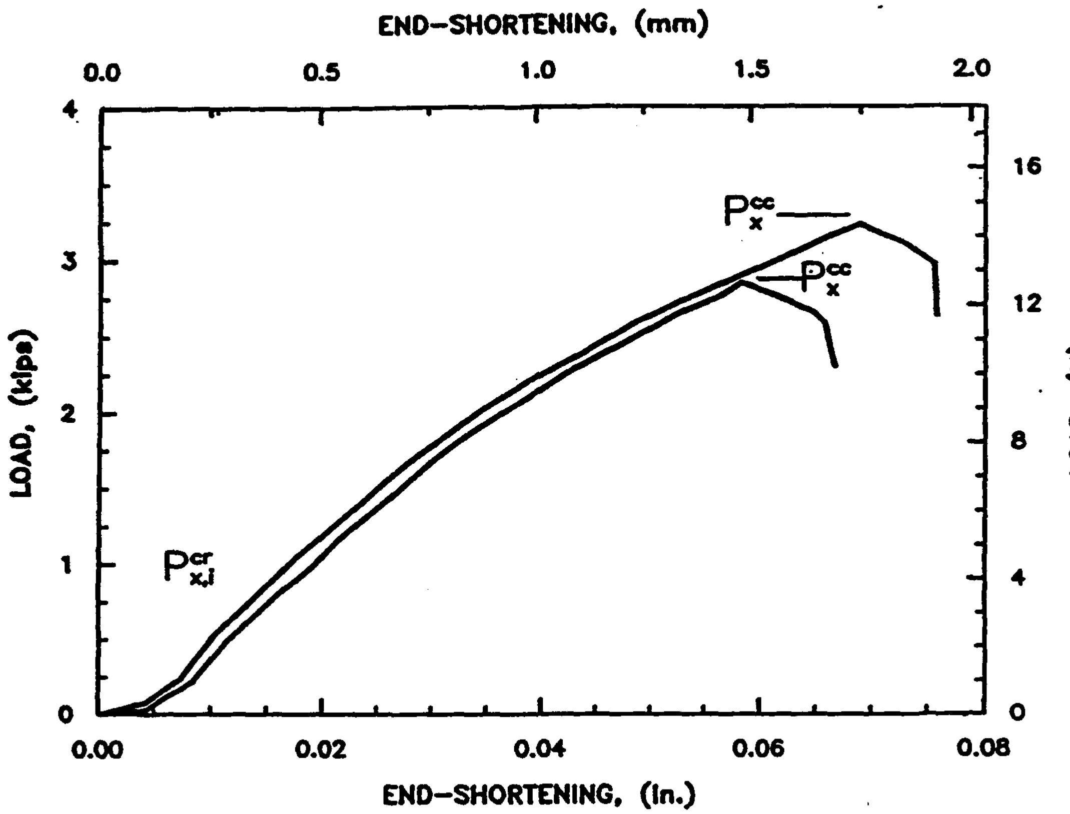


FIGURE 4.7.2(e) *One-edge-free plate. Crippling tests - AS/3501-6 [±45/90/0$_3$]$_s$ - b/t = 30.*

References 4.7.2(b) - (e)). The theoretical buckling curves shown in Figure 4.7.2.1(c) are very conservative at high b/t values and very unconservative at low b/t values.

4.7.2.2 *Fatigue effects.* Postbuckling fatigue may be permitted under certain circumstances without jeopardizing the structural integrity of the plate: References 4.7.2(b), 4.7.2(h), and 4.7.2(i). Significant conclusions identified in Reference 4.7.2(i) stated: "Composite panels demonstrated a high fatigue threshold relative to the initial skin buckling loads. Composite panels showed a greater sensitivity to shear dominated fatigue loading as compared with

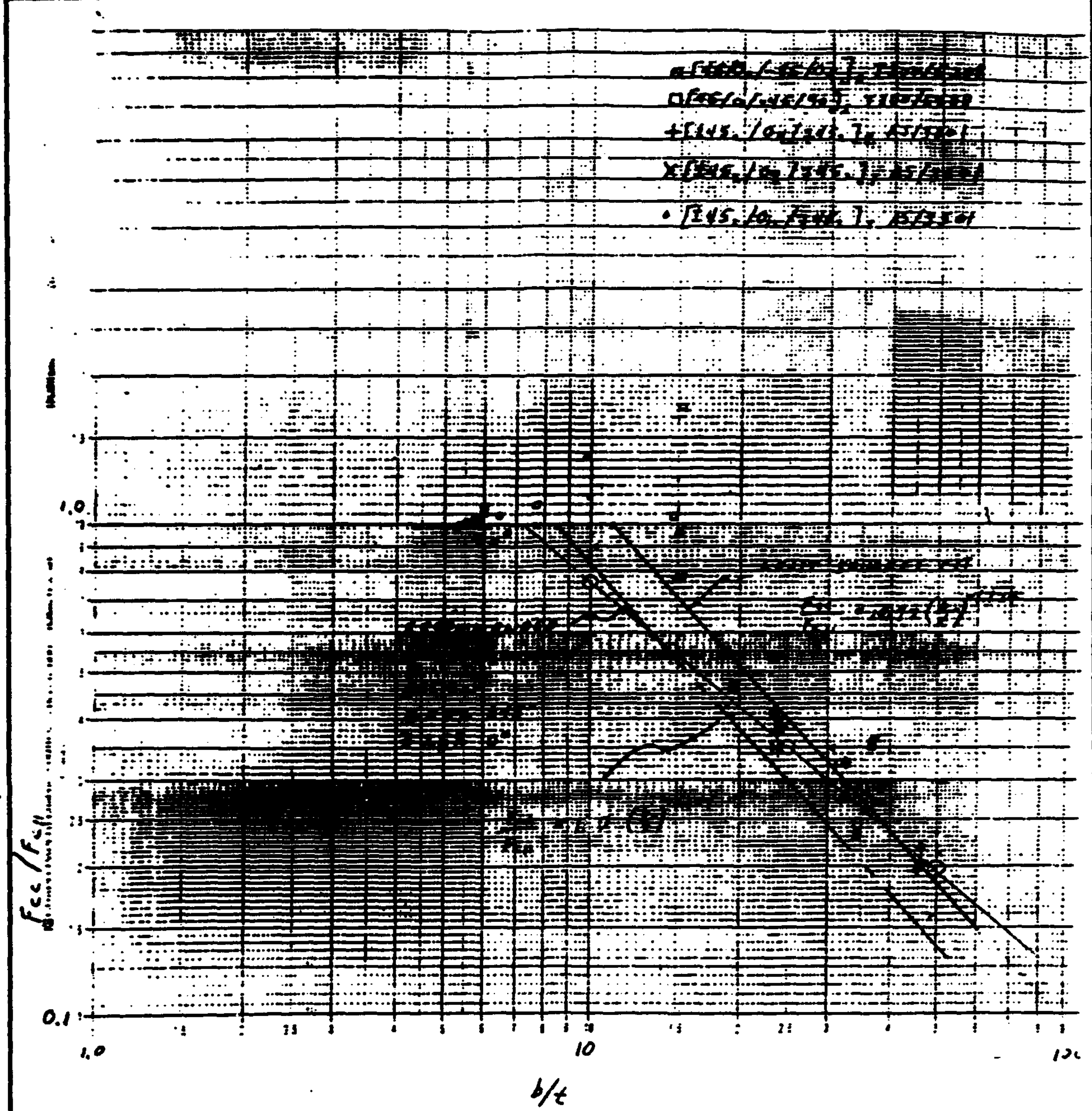


FIGURE 4.7.2(f) *Normalized crippling data - no-edge-free.*

compression dominated fatigue loading. The fatigue failure mode in composite panels was separation between the cocured stiffener and skin."

4.7.2.3 *Allowable crippling curve determination.* Crippling data can be normalized by the laminate compression strength to produce crippling curves valid for different lay-ups, as shown in Figures 4.7.2(f) and 4.7.2(h). This normalization technique works for laminates between 25-70% ±45 plies but does not work with all ±45, all 0, or all 0/90 laminates. A lower bound is shown in the figures through the lowest test point. A more accurate method

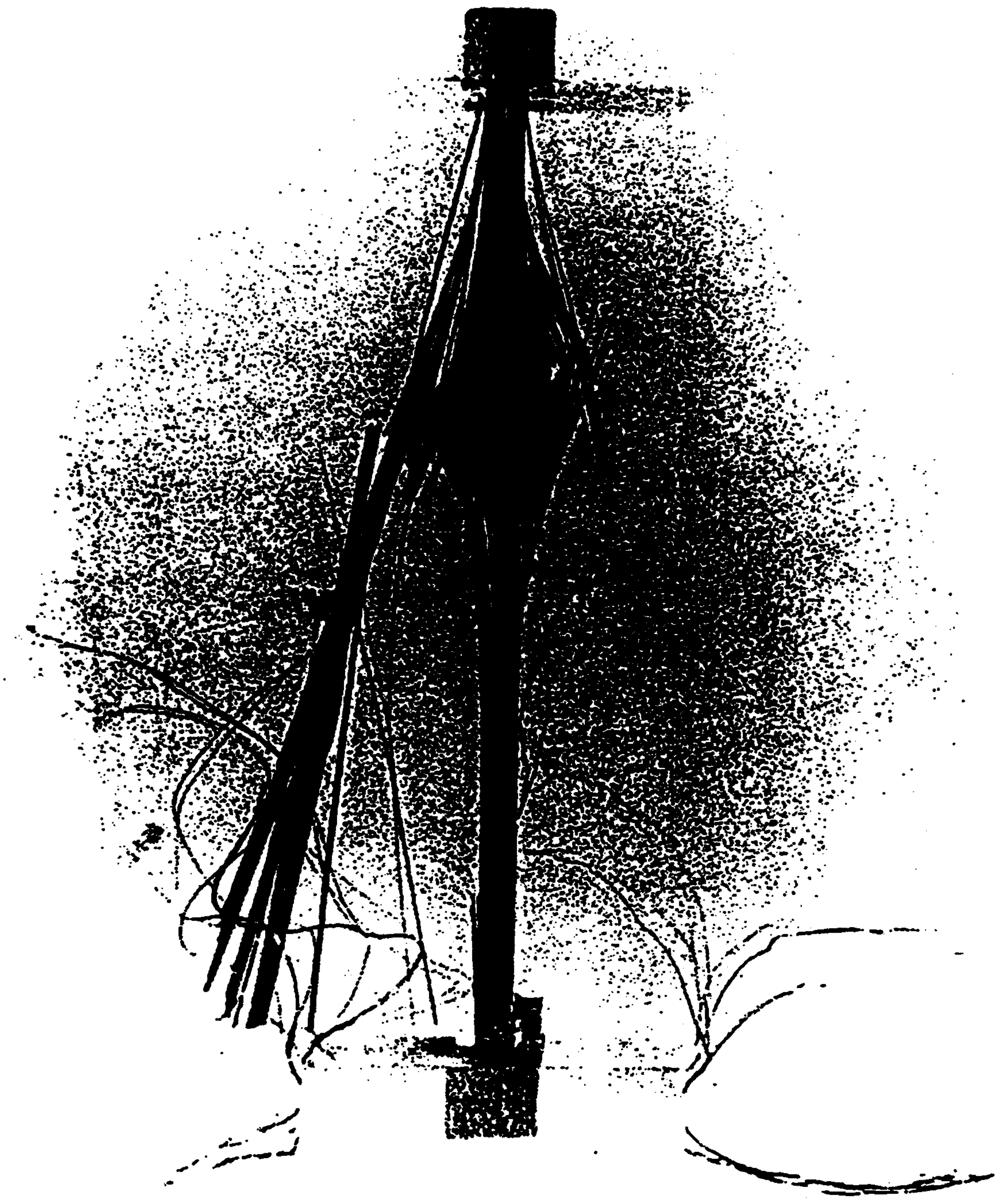


FIGURE 4.7.2(g) *Typical graphite/epoxy failed ultimate compression specimen.*

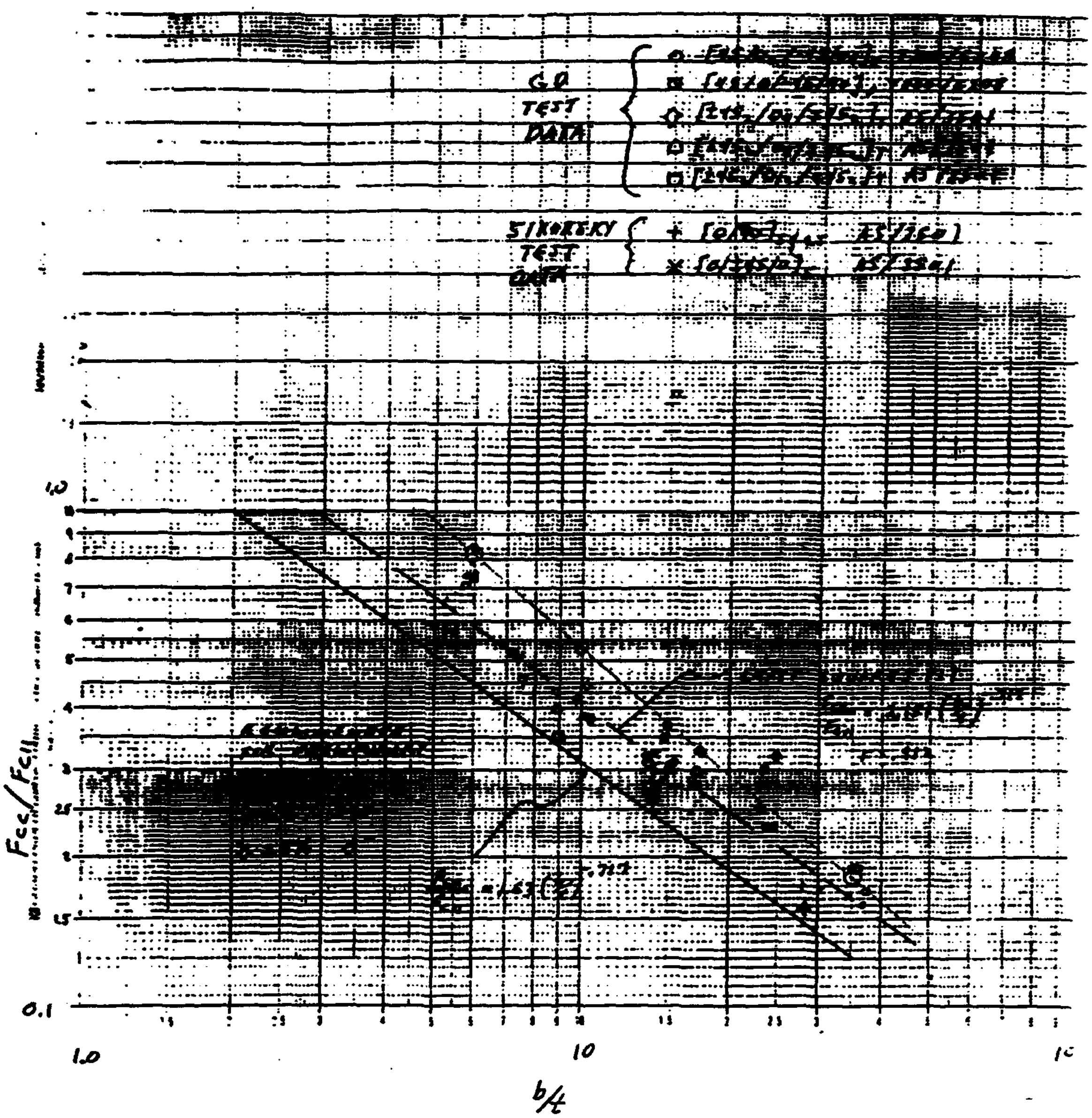


FIGURE 4.7.2(h) *Normalized crippling data - one-edge free.*

of determining an allowable crippling curve is to obtain a lower bound based on a 99 or 95% confidence level for the regression, resulting in an A or B allowable curve. Examples are given in Figures 4.7.2.3(a) and 4.7.2.3(b).

4.7.2.4 *Crippling strength determination.* The crippling strength of each segment is calculated based on the segment's length/thickness ratio (b/t), its boundary conditions (one-edge-free or no-edge-free), and the compression strength of the laminate (F^c_{11}). Figures 4.7.2.3(a) and 4.7.2.3(b) give one-edge-free and no-edge-free allowable crippling curves

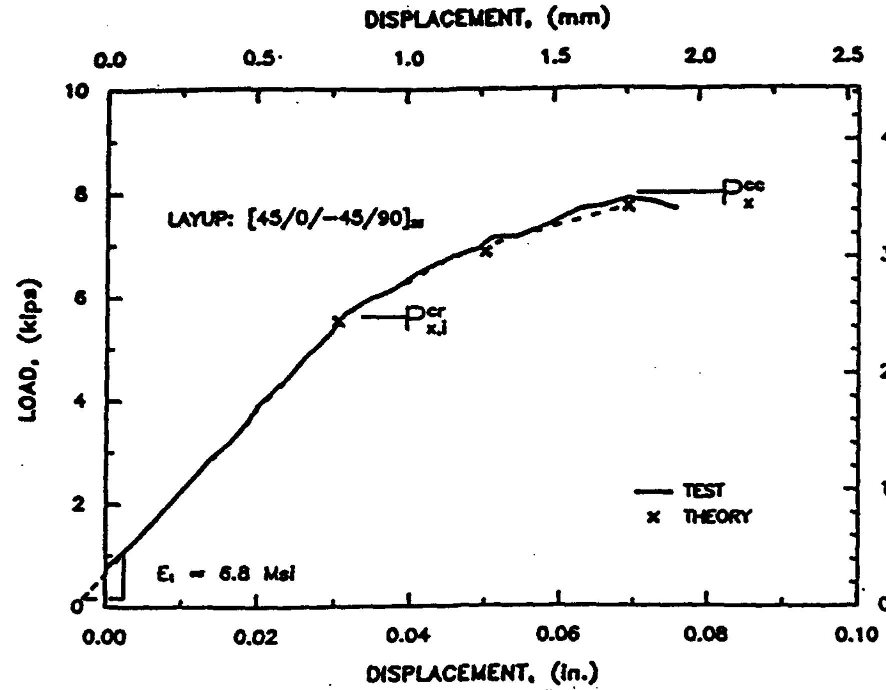


FIGURE 4.7.2.1(a) *Comparison of theory in References 4.7.1.3(b) and (c) with experiments for postbuckling curves and crippling strengths.*

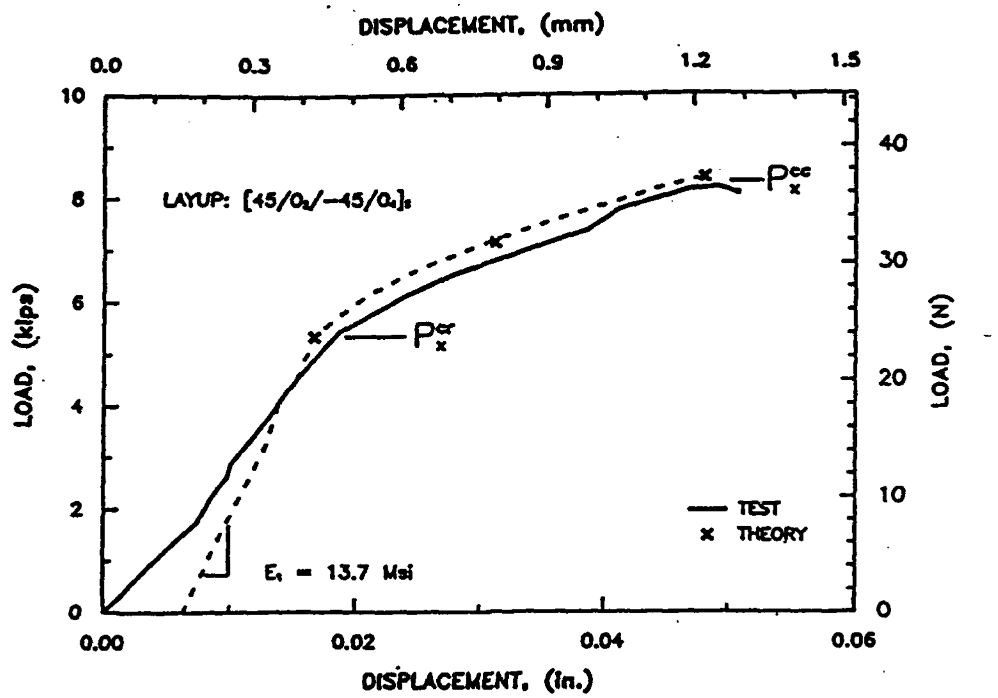


FIGURE 4.7.2.1(b) *Comparison of theory in References 4.7.1.3(b) and (c) with experiments for postbuckling curves and crippling strengths.*

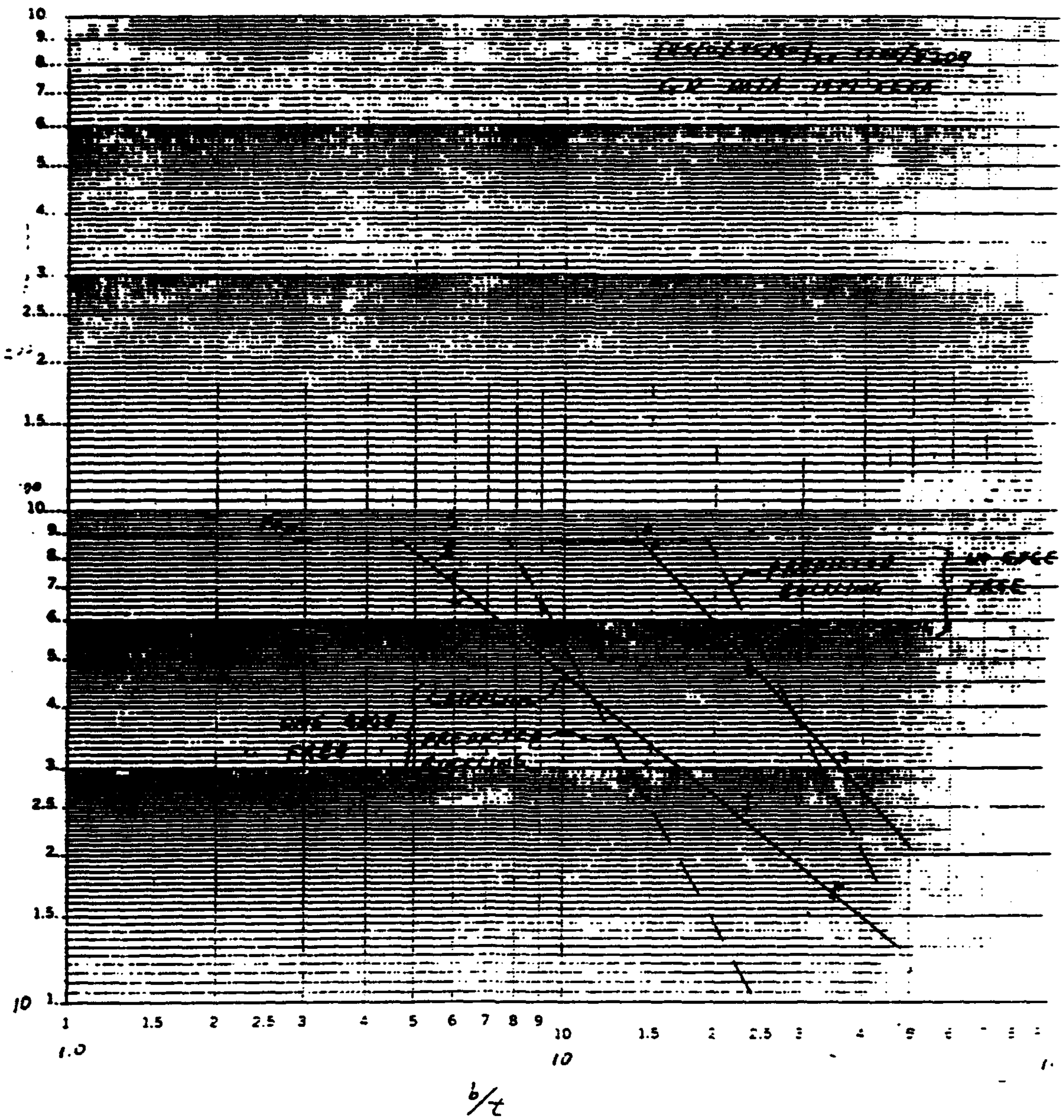


FIGURE 4.7.2.1(c) *Comparison of predicted buckling and crippling curves.*

applicable to typical AS4/3501 and T300/5208 graphite epoxy stiffeners. F^{cc}/F^{c}_{11} for each segment is read from the curves at the given b/t ratio. The F^{cc} is then calculated as:

$$F^{cc} = \left(F^{cc}/F^{c}_{11}\right) \cdot F^{c}_{11} \qquad 4.7.2.4(a)$$

The crippling strength of a stiffener composed of several segments is determined as the weighted sum of the crippling strengths of its segments:

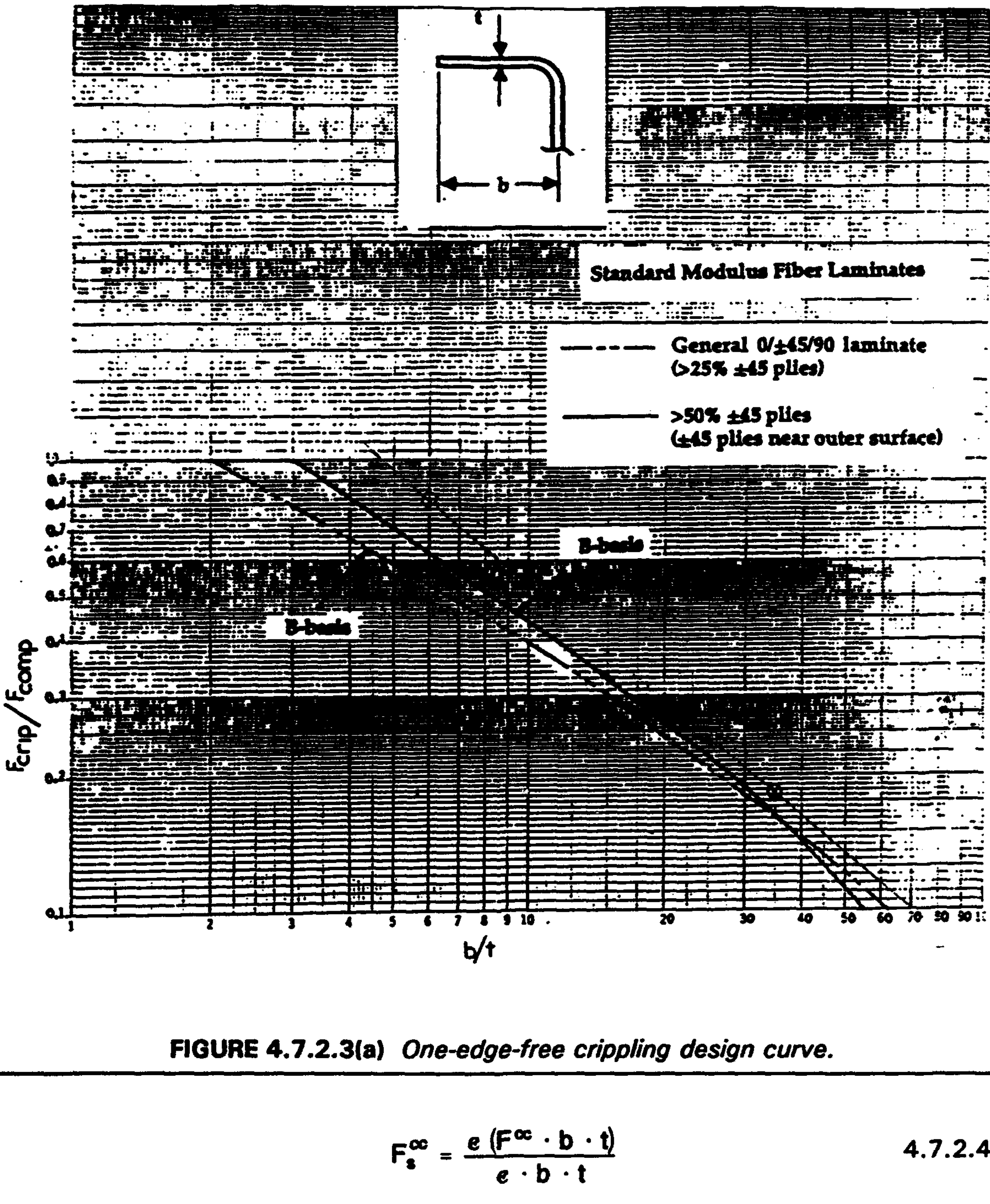


FIGURE 4.7.2.3(a) *One-edge-free crippling design curve.*

$$F_s^{cc} = \frac{e\,(F^{cc} \cdot b \cdot t)}{e \cdot b \cdot t} \qquad 4.7.2.4(b)$$

Where b and t are the width and thickness of each segment of the stiffener. The stiffener crippling stress F_s^{cc} is subject to the limitation that no segment F^{cc} may be less than 3/4 of the stiffener F_s^{cc}, otherwise C_{ccs} is limited to the minimum F^{cc} of any segment.

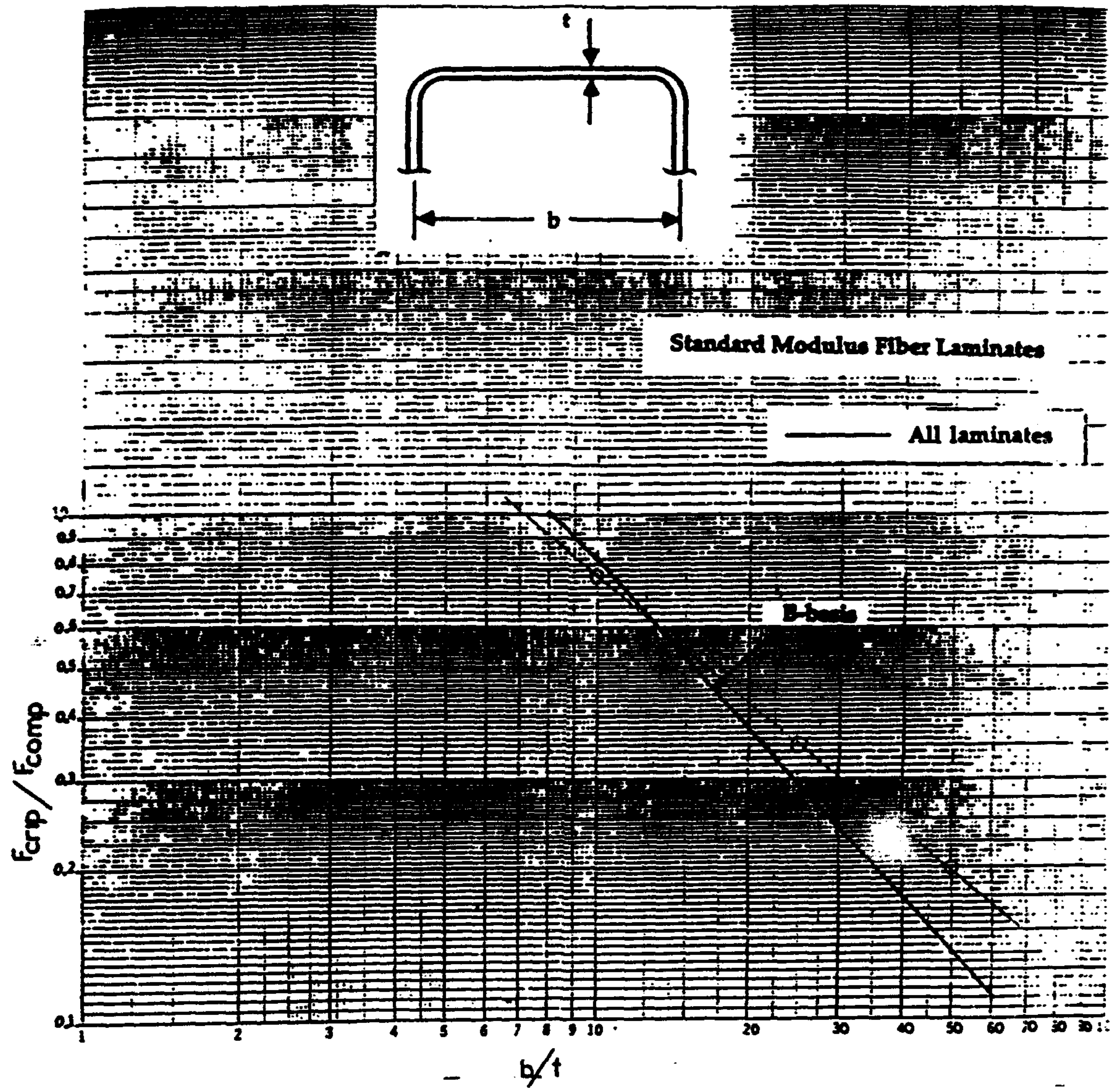


FIGURE 4.7.2.3(b) *No-edge-free crippling design curve.*

4.7.3 Column stability. New section.

4.7.4 Shear stability and postbuckling. New section.

REFERENCES

4.7.2(a) Spier, E.E., "On Experimental Versus Theoretical Incipient Buckling of Narrow Graphite/Epoxy Plates in Compression", AIAA-80-0686-Paper, published in Proceedings of AIAA/ASME/ASCE/AHS 21st Structures, Structural Dynamics, & Materials Conference, May 12-14, 1980, pp. 187-193.

4.7.2(b) Spier, E.E., "Local Buckling, Postbuckling, and Crippling Behavior of Graphite-Epoxy Short Thin Walled Compression Members", Naval Air Systems Command Report NASC-N00019-80-C-0174, June 1981.

4.7.2(c) Spier, E.E., "On Crippling and Short Column Buckling of Graphite/Epoxy Structure with Arbitrary Symmetrical Laminates", Presented at SESA 1977 Spring Meeting, Dallas, TX, May 1977.

4.7.2(d) Spier, E.E. and Klouman, F.K., "Post Buckling Behavior of Graphite/Epoxy Laminated plates and Channels", Presented at Army Symposium on Solid Mechanics, AMMRC MS 76-2, Sept. 1976.

4.7.2(e) Renieri, M.P. and Garrett, R.A., "Investigation of the Local Buckling, Postbuckling and Crippling Behavior of Graphite/Epoxy Short Thin-Walled Compression Members", McDonnell Aircraft Report MDC A7091, NASC, July 1981.

4.7.2(f) Bonanni, D.L., Johnson, E.R., and Starnes, J.H., "Local Crippling of Thin-Walled Graphite-Epoxy Stiffeners", AIAA Paper 88-2251.

4.7.2(g) Sikorsky data (Dobyns) need reference

4.7.2(h) Spier, E.E., "Postbuckling Fatigue Behavior of Graphite-Epoxy Stiffeners", AIAA Paper 82-0779-CP, AIAA/ASME/ASCE/AHS, published in the Proceedings of the 23rd Structures, Structural Dynamics, & Materials Conference, New Orleans, LA, May 1982, pp. 511-527.

4.7.2(i) Deo, R.B., et al, "Design Development and Durability Validation of Postbuckled Composite and Metal Panels", Air Force Flight Dynamics Laboratory Report, WRDC-TR-89-3030, 4 Volumes, November 1989.

Chapter 7 - Thick Section Composites

7.1 Introduction and Definition of Thick Section Composites

7.2 Mechanical Properties Required for Thick-Section 3-D Analysis

7.2.1 2-D Composite Analysis

7.2.2 3-D Composite Analysis

7.2.2.1 Unidirectional lamina 3-D properties
7.2.2.2 Oriented orthotropic laminate 3-D properties

7.2.3 Experimental property determination

7.2.4 Theoretical property determination

7.2.4.1 3-D lamina property determination
7.2.4.2 3-D laminate property determination

7.2.5 Test Specimen Design Considerations

7.3 Structural Analysis Methods for Thick-Section Composites

7.3.1 Three-Dimensional Elasticity Methods

7.3.2 Approximate Analytical Methods

7.3.3 Finite Element Methods

7.4 Physical Property Analysis Required for Thick-Section Composite Three-Dimensional Analysis

7.4.1 Experimental Property Determination

7.5 Process Analysis Methods for Thick-Section Composites

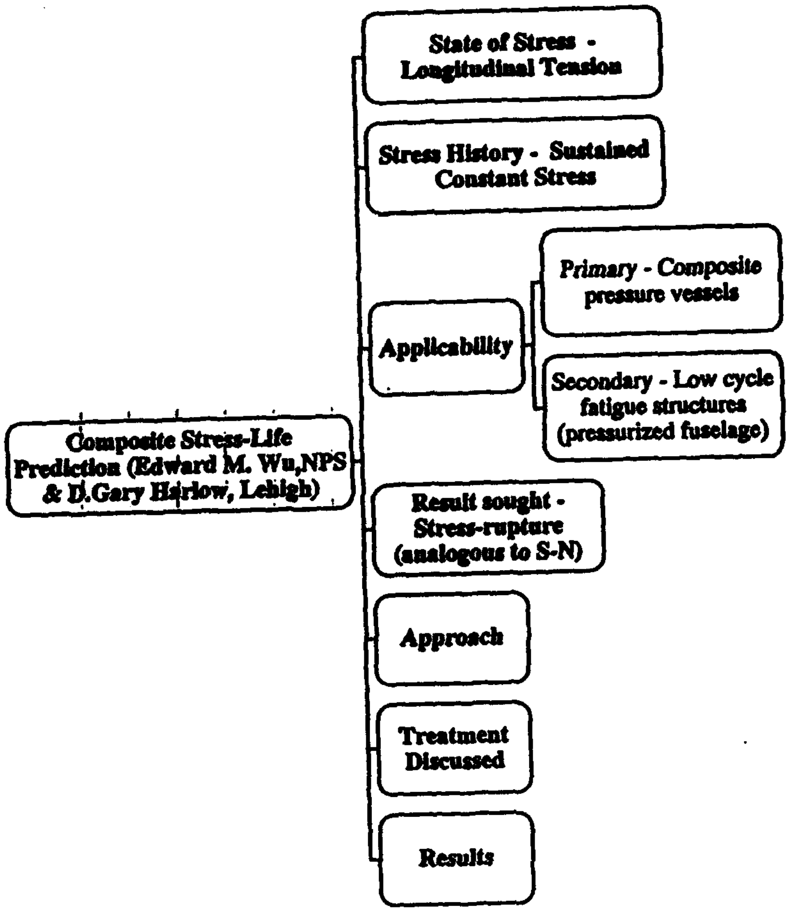
7.5.1 Introduction to Process Simulation

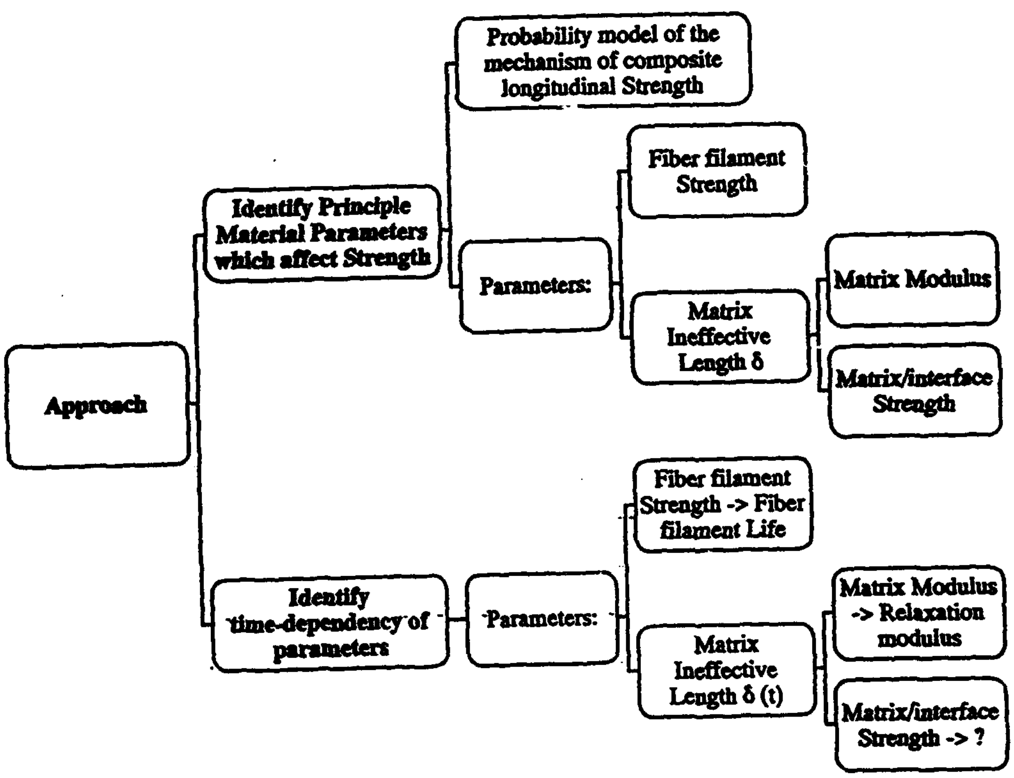
7.5.1.1 The Need for Process Simulation
7.5.1.2. Current State of the Art

7.5.2 Process Analysis Development

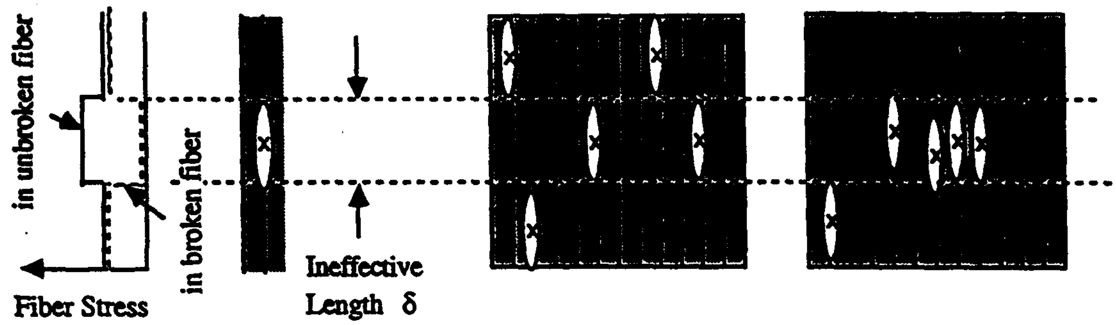
7.5.2.1 Generic Process Simulation Approach
7.5.2.2 Process Experiment for a Fabrication Method
7.5.2.3 Identify Dominant Process Mechanisms

5. PRESENTATIONS


Composite Stress-Life Prediction (Edward M. Wu,NPS & D.Gary Harlow, Lehigh)
State of Stress - Longitudinal Tension
Stress History - Sustained Constant Stress
Applicability
Primary - Composite pressure vessels
Secondary - Low cycle fatigue structures (pressurized fuselage)
Result sought - Stress-rupture (analogous to S-N)
Approach
Treatment Discussed
Results

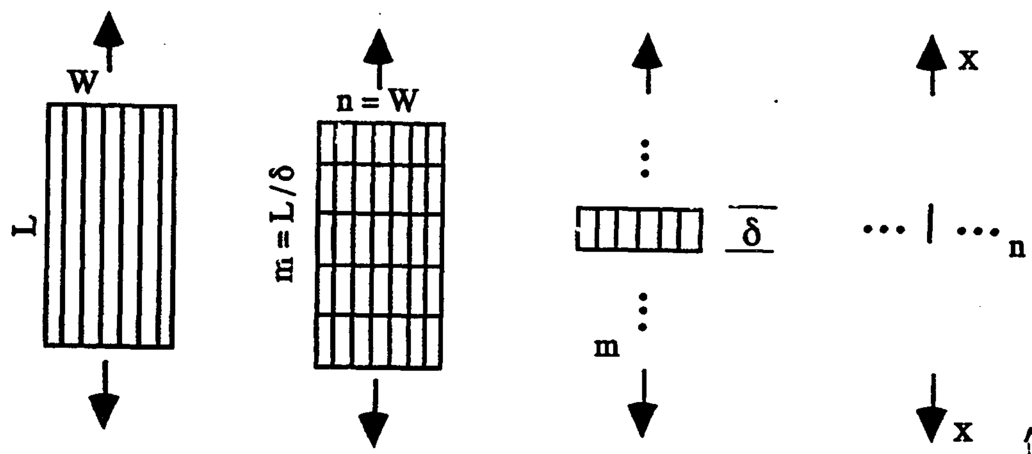

Approach
Identify Principle Material Parameters which affect Strength
Probability model of the mechanism of composite longitudinal Strength
Parameters:
Fiber filament Strength
Matrix Ineffective Length δ
Matrix Modulus
Matrix/interface Strength
Identify time-dependency of parameters
Parameters:
Fiber filament Strength -> Fiber filament Life
Matrix Ineffective Length δ (t)
Matrix Modulus -> Relaxation modulus
Matrix/interface Strength -> ?

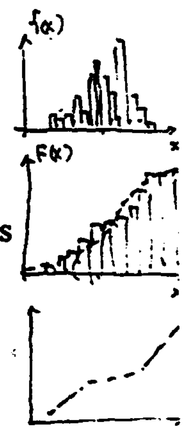
Local Load Sharing around broken fibers cummulating to flaw clustering



Local Load Sharing of a Broken Fiber	Dispersed Flaws Strong Composite	Clustered Flaws Weak Composite
(a)	(b)	(c)

Ref: Rosen, Harlow-Phoenix . . .



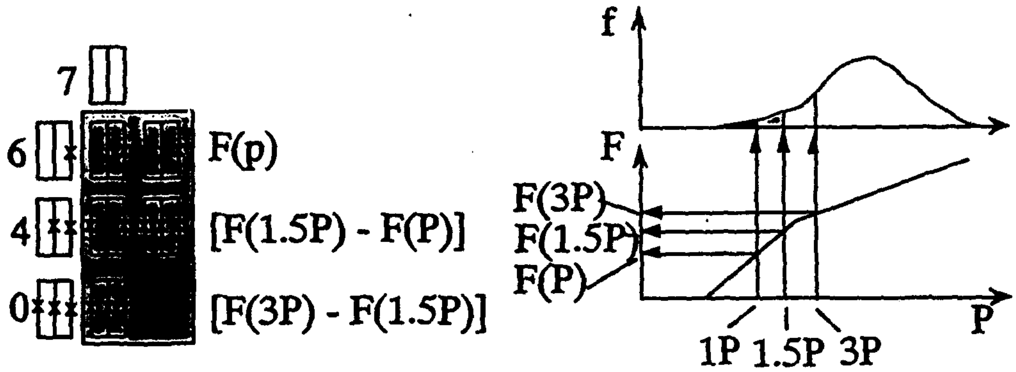


$H_{m,n}(x)$	$G_n(x)$	$F(x)$
Composite in terms of Physical dimensions	Dimensions in terms of Strength metric δ length m, width n	Lengthwise mth Links	Widthwise nth Elements
(a)	(b)	(c)	(d)

Partitioning of Composite for Strength Characterizaton

$H_{m,n}(x) = 1 - [(1 - G_n^k(x))]^m$

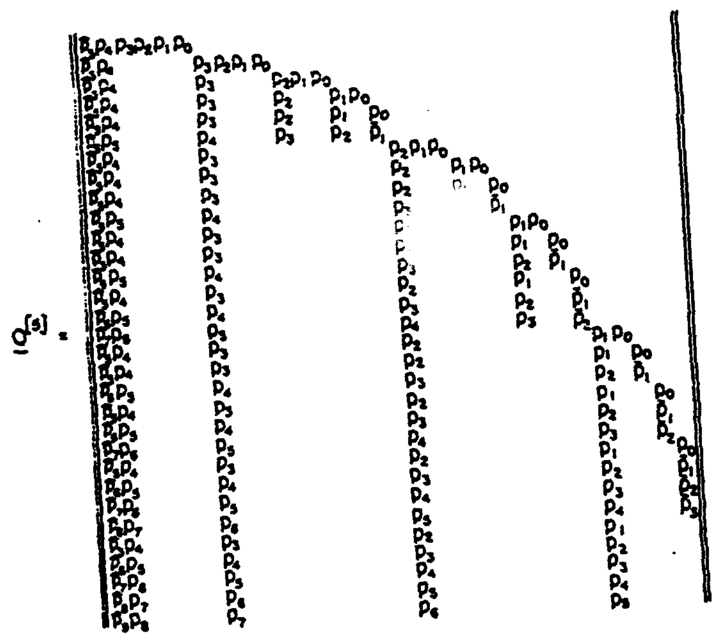
Probability of the occurrence of the individual parts of the sequence 7640 are:



Probability of Failure can be quantified given *either* :

Analytical Model, say Weibull $F(P)= 1-\exp\{-(P/\beta)^{\alpha}\}$, *or*

Numerical Model, Uni or Multi modal

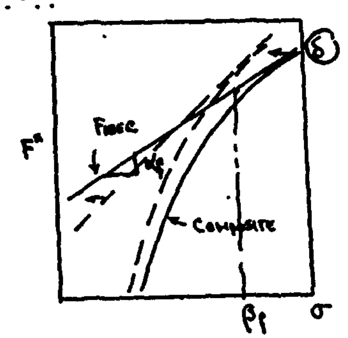


$$G_n^{[k]}(x) = 1 - Q_n^{[k]}(x), \quad x \geqq 0$$

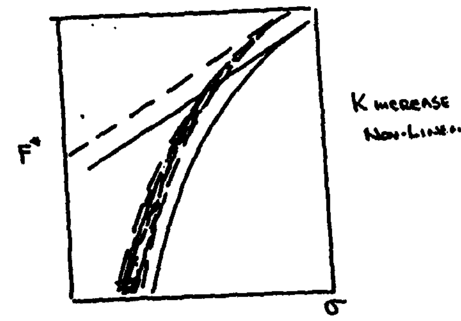
$$Q_n^{[k]}(x) = \sum_{j=1}^{2^{k-1}} \{\underline{Q}^{[k]}(x)\}_{1j}^{n}$$

Effect of Time dependency of parameters on Composite Strength/Life

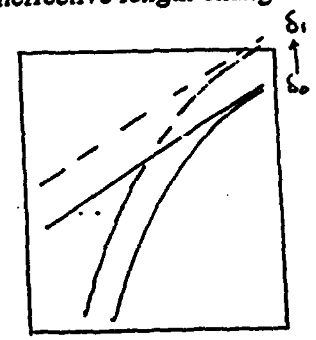
Fiber Strength change



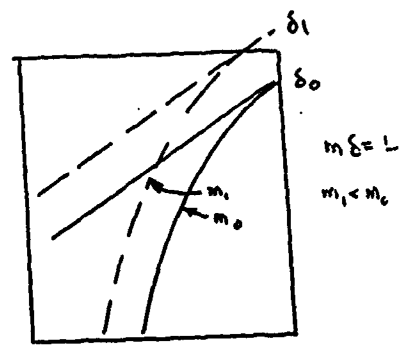
Fiber Strength time-dependent



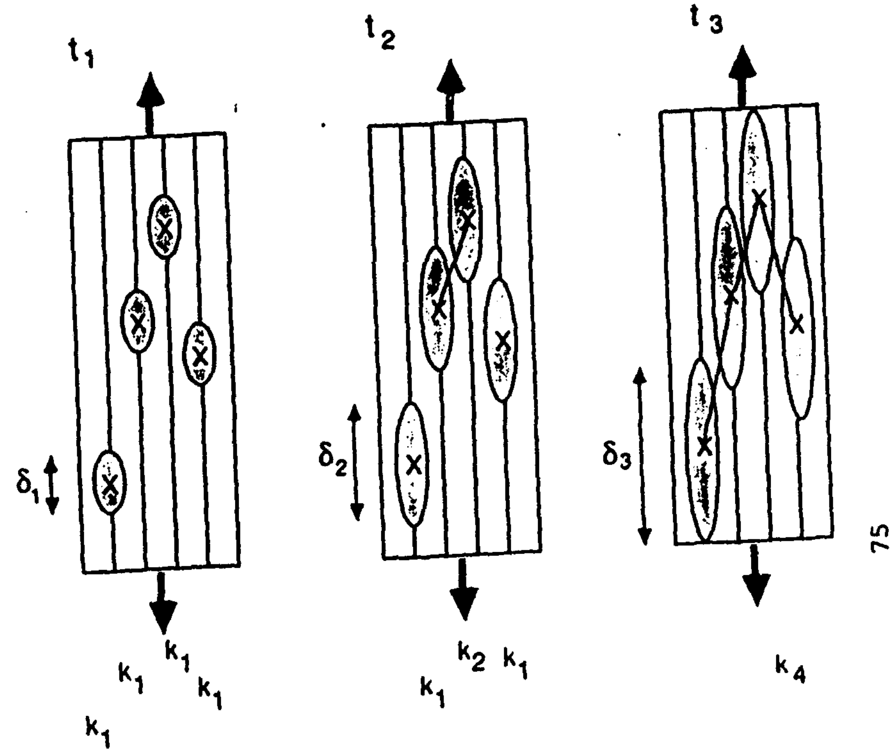
Ineffective length change



Ineffective length time dependent



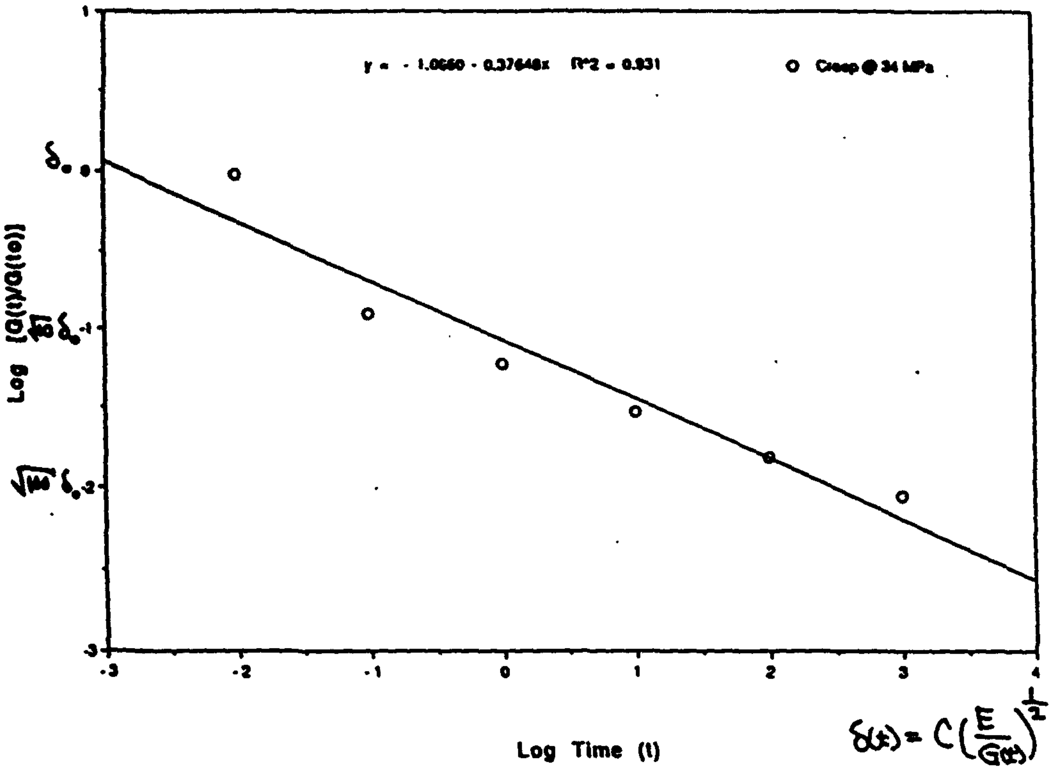
Effect of Time-dependent increase in ineffect length δ on composite strength instability



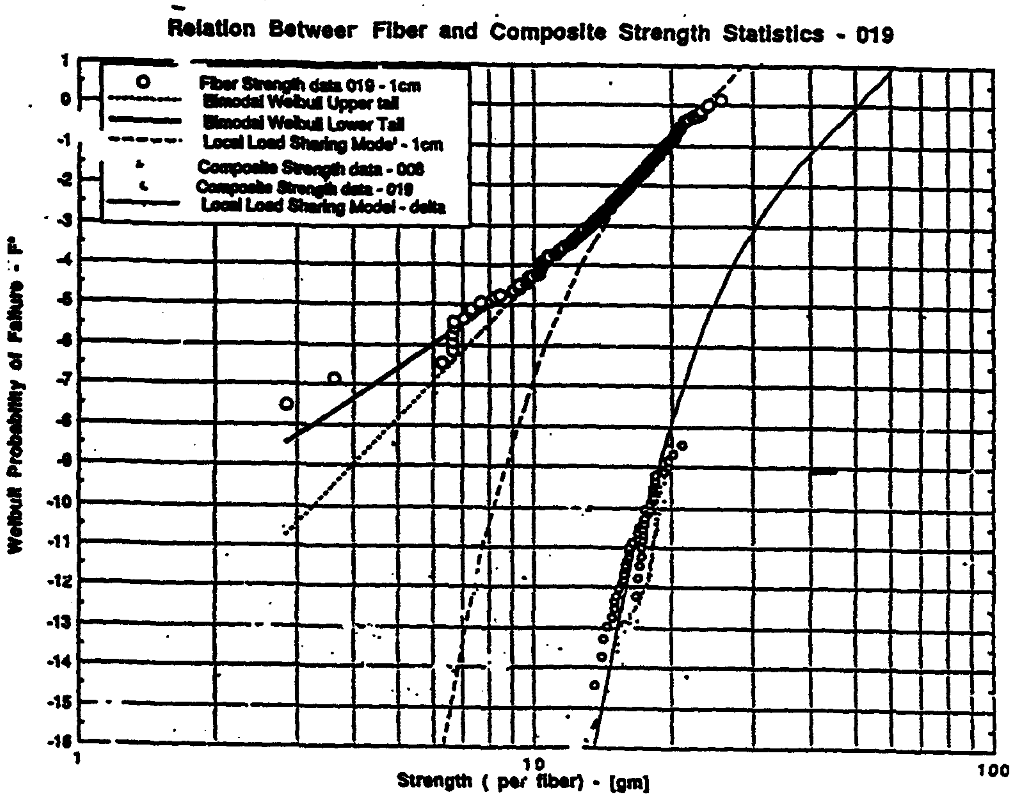
k_1 - 1 contiguous break
K_2 - 2 contiguous breaks
K_c - c contiguous breaks lead to ultimate instability

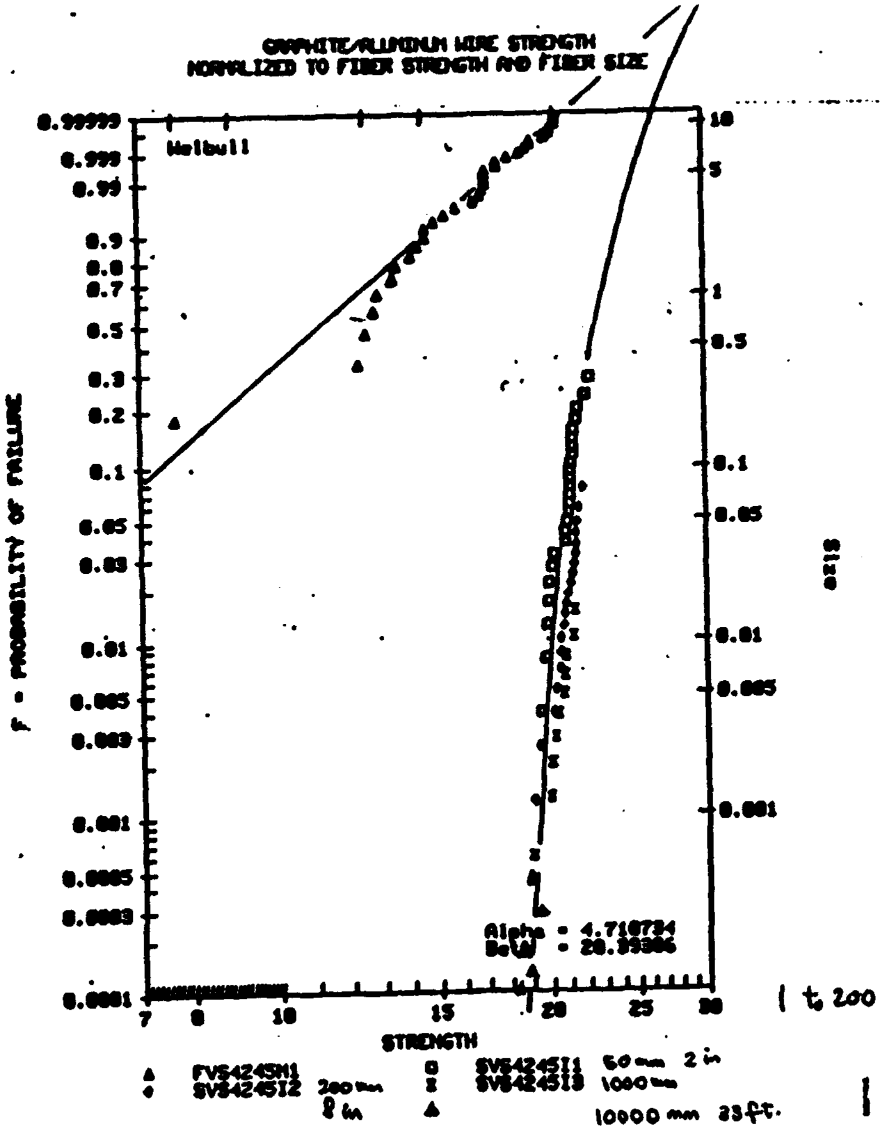
K_n Increases in time (caused by δ increase) even when there is no additional filament break.

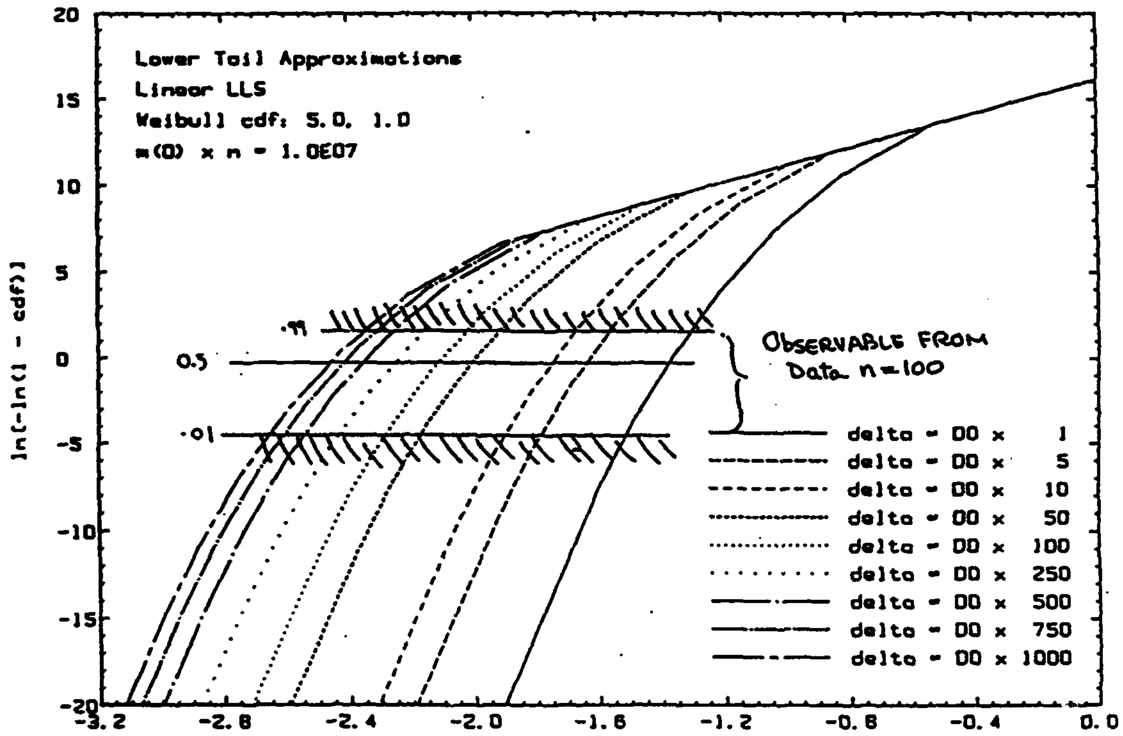
$$\delta(t) = 1.15\, d_f \left(\frac{1-V_f^{\frac{1}{2}}}{V_f^{\frac{1}{2}}}\right)^{\frac{1}{2}} \left(\frac{E_f(t)}{G_m(t)}\right)^{\frac{1}{2}}$$ ELASTIC ANALYSIS

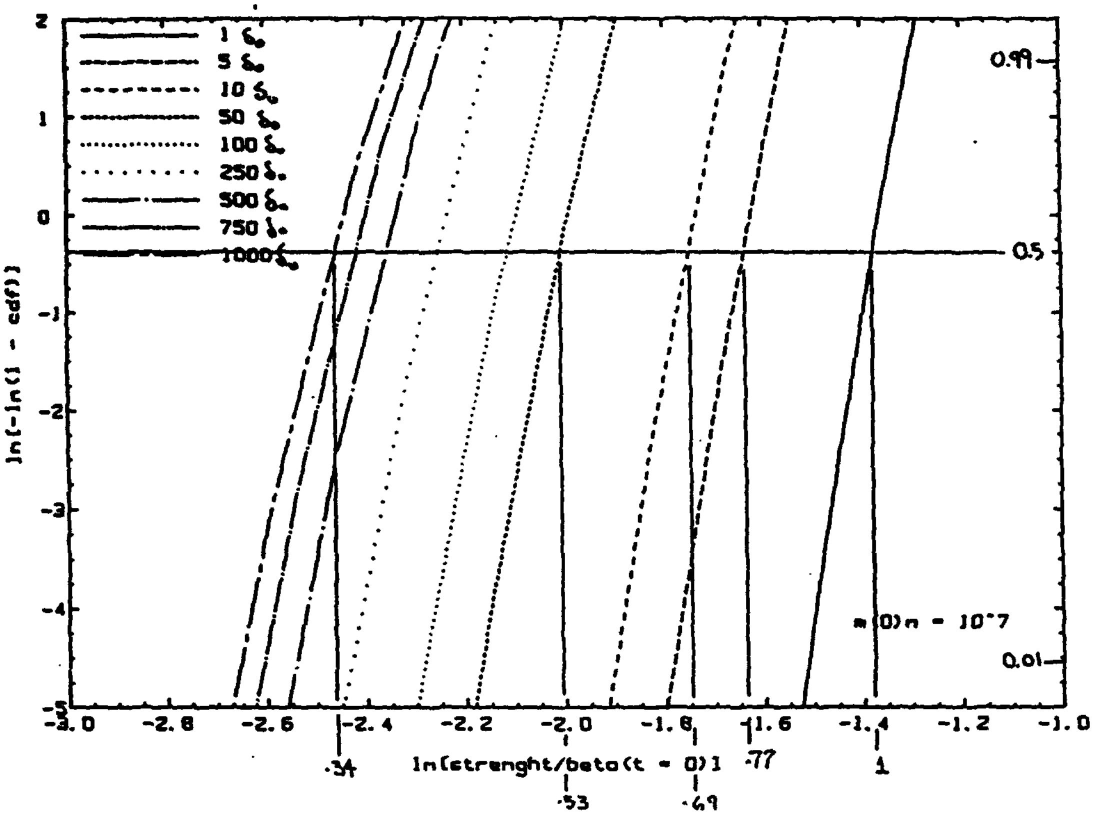


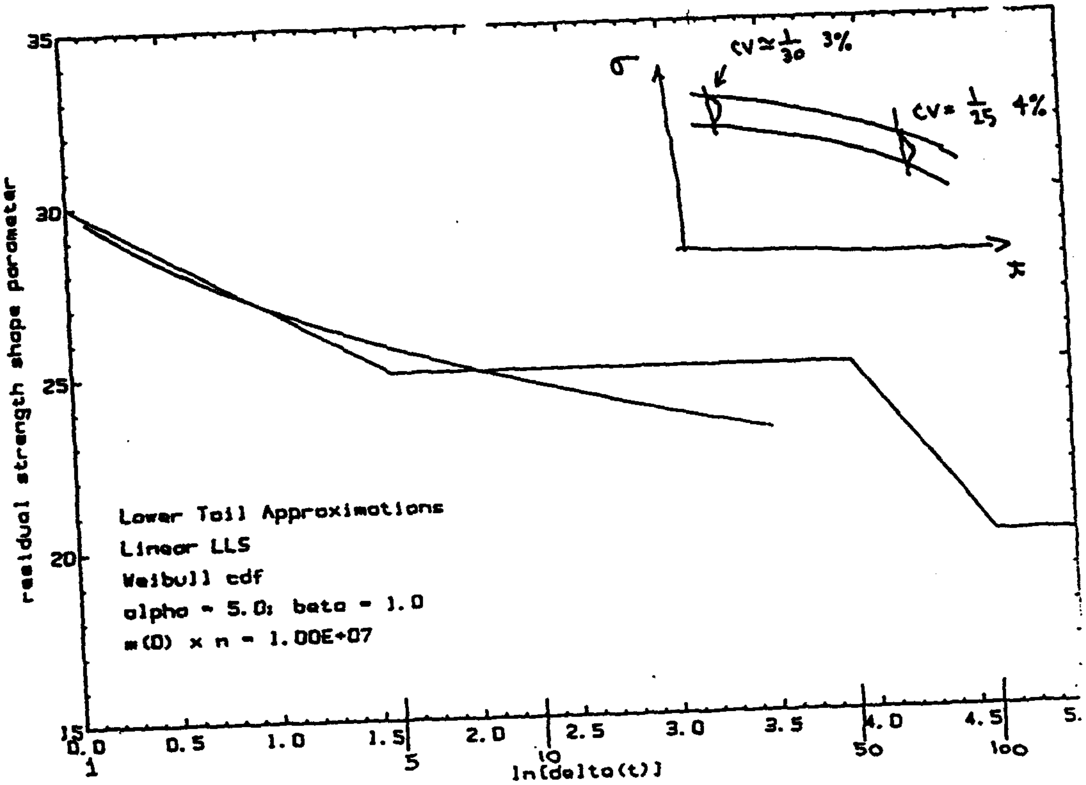
Cycloaliphatic Epoxy Creep - Data from R.H. Ericksen (1976) Composite 7

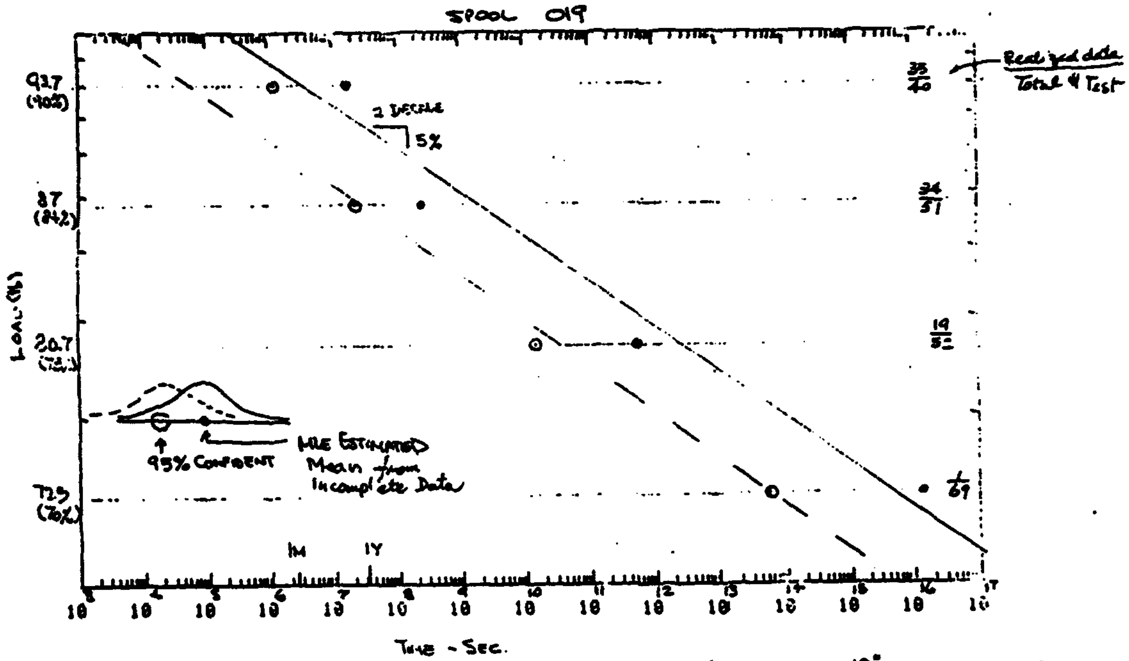



GRAPHITE/ALUMINUM WIRE STRENGTH
NORMALIZED TO FIBER STRENGTH AND FIBER SIZE
Weibull
F = PROBABILITY OF FAILURE
STRENGTH
SIZE
Alpha = 4.718734
Beta = 20.39306
t, 200
FVS4245M1
SV54245I2 200 mm 8 in
SV54245I1 50 mm 2 in
SV54245I3 1000 mm
10000 mm 33 ft.


Lower Tail Approximations
Linear LLS
Weibull cdf: 5.0, 1.0
m(D) x n = 1.0E07
ln[-ln(1 - cdf)]
ln[strenght/beta(t = D)]
.99
0.5
.01
OBSERVABLE FROM Data n=100
delta = DD x 1
delta = DD x 5
delta = DD x 10
delta = DD x 50
delta = DD x 100
delta = DD x 250
delta = DD x 500
delta = DD x 750
delta = DD x 1000


1 δ_0
5 δ_0
10 δ_0
50 δ_0
100 δ_0
250 δ_0
500 δ_0
750 δ_0
1000 δ_0
0.99
0.5
0.01
m(0)n = 10^7
ln[-ln(1 - cdf)]
ln[strenght/beta(t = 0)]
.34
.53
.69
.77
1


residual strength shape parameter
Lower Tail Approximations
Linear LLS
Weibull cdf
alpha = 5.0; beta = 1.0
m(0) x n = 1.00E+07
ln[delta(t)]
CV ≈ 1/30 3%
CV = 1/25 4%



AS4 Graphite/Epoxy (DER 332/T403) Strand 10"

Treatment Discussed

1. **Effect of time-dependent loss of interfacial effectiveness**
2. **Range of ineffective length change for observed composite life data**
3. **Range of ineffective length change attributed to matrix viscoelatic effect**
4. **Results**
   - 4.1. Model can predict median life (strength degradation) through appropriate ineffective length δ growth function
   - 4.2. Model yields life dispersion increase for low stress/long time
   - 4.3. Fiber Life degradation will provide addition account for general variations in life dispersion.
   - 4.4. May be applicable for Certification Methodology

COMPOSITE AIRCRAFT STRUCTURES

- DESIGN PHILOSOPHY
- DESIGN CRITERIA
- DESIGN PROCEDURES
- VALIDATION TESTING

IS SOME FORM OF STANDARDIZATION DESIRABLE ?

IF SO, SHOULD MIL-HDBK-17 TAKE A LEAD ROLE ?

OBSERVATIONS / OPINIONS

- PHILOSOPHY AND CRITERIA USED IN THE DESIGN OF COMPOSITE STRUCTURES DIFFER WIDELY BETWEEN COMPANIES AND OFTEN BETWEEN PROJECTS WITHIN THE SAME COMPANY.
- IN MANY CASES, THE CRITERIA THAT ARE USED LEAD TO OVERLY CONSERVATIVE DESIGNS, WHICH IS ONE OF THE REASONS WHY THE WEIGHT-SAVINGS POTENTIAL OF COMPOSITE STRUCTURES HAVE NOT BEEN ACHIEVED.
- A SOMEWHAT CONSERVATIVE DESIGN PHILOSOPHY IS BOTH PRUDENT AND NECESSARY WITH COMPOSITE STRUCTURES BUT THE GOVERNING CRITERIA SHOULD ALWAYS BE REALISTIC AND REFLECT AN UNDERSTANDING OF THE CRITICAL FAILURE MODES AND MECHANISMS THAT CAUSE FAILURES.

DESIGN PHILOSOPHY AND CRITERIA

- STANDARDIZATION NEEDS TO COVER STRUCTURAL DESIGN ONLY WITH AN EMPHASIS ON "SAFETY-OF-FLIGHT" ISSUES.

- DESIGN CRITERIA ARE ESTABLISHED BASED ON A CHOSEN DESIGN PHILOSOPHY AND THEREFORE THE TWO ARE INSEPARABLE.

- MORE UNIFORM DESIGN CRITERIA WILL BENEFIT THE AEROSPACE COMMUNITY BECAUSE TECHNOLOGY TRANSFER AND EXCHANGE OF DATA BETWEEN PARTNERS, TEAM MEMBERS, CUSTOMERS, AND THE CERTIFYING AGENCY WILL BE SIMPLIFIED CONSIDERABLY.

- MORE REALISTIC AND LESS CONSERVATIVE CRITERIA WILL HELP TO ACHIEVE THE WEIGHT-SAVINGS POTENTIAL OF COMPOSITES.

DESIGN PHILOSOPHY - EXAMPLES

LAMINATE DESIGN:

HOW DO WE GET FROM PLY-LEVEL MATERIAL DATA TO LAMINATE DESIGN ALLOWABLES?

BUCKLED VERSUS UNBUCKLED DESIGN:

WHAT COMPONENTS OR SUBCOMPONENTS ARE ALLOWED TO BUCKLE AND AT WHAT LOAD LEVELS?

DAMAGE TOLERANCE DESIGN:

GROWTH VERSUS NO-GROWTH PHILOSOPHY

DESIGN PHILOSOPHY - OTHER ISSUES

- WHAT CONSTITUTES FAILURE OF A LAMINATE?
- SHOULD MATRIX CRACKING BE PERMITTED ABOVE LIMIT LOAD?
- ACCOUNT FOR RESIDUAL THERMAL STRESSES DUE TO CURING?
- TYPE OF DESIGN ALLOWABLES TO BE GENERATED.
- HOW TO HANDLE COMBINED LOAD EFFECTS.
- SCALE-UP FROM COUPONS TO REAL STRUCTURE.

DESIGN CRITERIA - EXAMPLES

- STATIC LOADING - ALLOWABLE STRESS OR STRAIN LEVELS.
- COMBINED LOADS - INTERACTION EQUATIONS TO DETERMINE MARGINS OF SAFETY.
- CYCLIC LOADING - REDUCED STRESS OR STRAIN ALLOWABLES.
- JOINT DESIGN - BEARING/BYPASS INTERACTION CURVES TO DETERMINE MARGINS OF SAFETY, MINIMUM EDGE DISTANCES, FASTENER SPACINGS.
- STABILITY - BEAM COLUMNS, ECCENTRIC LOADING, PANELS, ALLOWABLE LEVELS OF POSTBUCKLING.
- DAMAGE TOLERANCE - TYPES OF DAMAGE, SIZE, LOCATIONS.
- MANUFACTURING DEFECTS - PERMISSABLE FLAWS, DISBONDS, ETC.

DESIGN PROCEDURES / VALIDATION TESTING

STANDARDIZATION OF ANALYTICAL METHODS TO BE USED IN DESIGN AND TESTS TO BE CONDUCTED MAY NOT BE PRACTICAL IN THE FORESEEABLE FUTURE.

INITIAL EFFORTS MAY HAVE TO BE LIMITED TO THE FOLLOWING:

- SPECIFY TYPES OF ANALYSIS TO BE PERFORMED AND TYPES OF TESTS THAT NEED TO BE CONDUCTED TO VALIDATE THE DESIGN.

- RECOMMEND AVAILABLE DESIGN PROCEDURES AND COMPUTER CODES THAT MAY BE USED IN CONJUNCTION WITH, OR IN LIEU OF, STRUCTURAL TESTS.

WHY SHOULD MIL-HDBK-17 LEAD SUCH AN EFFORT?

- MIL-HDBK-17 ALREADY HAS ESTABLISHED TECHNICAL COMMITTEES WHOSE MEMBERS REPRESENT THE AEROSPACE INDUSTRY AS WELL AS KEY GOVERNMENT AGENCIES.

- MIL-HDBK-17 REPRESENTATIVES HAVE, OR HAVE ACCESS TO, THE EXPERTISE THAT IS NEEDED TO ESTABLISH REALISTIC DESIGN CRITERIA IN AREAS INVOLVING "SAFETY-OF-FLIGHT" ISSUES.

- MIL-HDBK-17 CURRENTLY DEVELOPES GUIDELINES, RECOMMENDS TEST METHODS, AND PROVIDES DESIGN DATA TO INDUSTRY. THE PROPOSED EFFORT SHOULD THEREFORE BE WITHIN ITS CHARTER.

LAMINATE VERSUS PLY-LEVEL APPROACH

- LAMINATED COMPOSITES ARE HETEROGENEOUS AND ANISOTROPIC AND MANY OF THE CRITICAL FAILURE MODES IN COMPOSITE STRUCTURES ARE THE RESULT OF THIS FACT.

- MOST FAILURES INITIATE IN AREAS OF LOCAL DETAILS AND ARE CAUSED BY UNINTENTIONAL ECCENTRICITIES, OUT-OF-PLANE LOADS, STIFFENER RUNOUTS, ETC. THE COMMON DENOMINATOR IS LOCAL BENDING. LAY-UP AND STACKING SEQUENCE MAY BECOME IMPORTANT DESIGN CONSIDERATIONS.

- A LAMINATE DESIGN PHILOSOPHY IS GENERALLY BASED ON THE ASSUMPTION THAT THE LAMINATE IS IN A UNIFORM (MEMBRANE) STATE OF STRESS AND THEREFORE STACKING SEQUENCE EFFECTS ARE IGNORED. SINCE LAMINATE TESTING IS USUALLY LIMITED TO SIMPLE TENSION AND COMPRESSION, COMBINED LOAD EFFECTS ARE DIFFICULT TO EVALUATE.

LAMINATE VERSUS PLY-LEVEL APPROACH

- LAMINATE ANALYSIS PROCEDURES USING A PLY-LEVEL APPROACH ARE THE PREFERRED DESIGN TOOL SINCE, IN THEORY AT LEAST, THEY HAVE THE CAPABILITY TO ADDRESS MOST, IF NOT ALL, OF THE CRITICAL FAILURE MODES THAT MAY OCCUR IN COMPOSITE STRUCTURES.

- HOWEVER, MOST LAMINATE ANALYSIS METHODS IN USE TO-DAY, COMPUTE STRAINS AND STRESSES BASED ON LAMINATED PLATE THEORY AND THUS REQUIRE INPUT OF PLY-LEVEL DATA. SINCE PLY-LEVEL PROPERTIES ARE GENERALLY NON-LINEAR, ACCURATE PREDICTION OF LAMINATE BEHAVIOR IS NOT POSSIBLE WITH THESE METHODS.

COMBINED BENDING AND AXIAL LOADS

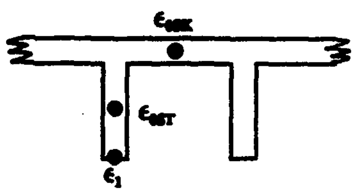
GIVEN:

DESIGN ALLOWABLE FOR IN-PLANE (MEMBRANE) LOADING

e.g. STRAIN CUT-OFF = $\bar{\epsilon}_M$

PROBLEM:

HOW TO COMPUTE MARGINS OF SAFETY FOR STIFFENED PANELS SUBJECTED TO COMBINED MEMBRANE AND BENDING LOADS.



$$M.S. = \frac{1}{\epsilon_0/\bar{\epsilon}_M + (\epsilon_1 - \epsilon_0)/\bar{\epsilon}_B} - 1.0$$

$\bar{\epsilon}_B = ?$

COMPOSITE MATERIAL CHARACTERIZATION / STRUCTURAL RESPONSE SIMULATOR

Presented to the MIL HDBK-17 Meeting
March 29, 1994

Mechanics of Materials Branch
Material Science and Technology Division
Naval Research Laboratory
Washington DC 20375-5000

OUTLINE

- Motivation
- Goals and Objectives
- Dissipated Energy Density
- Application of DED for simulation of structural specimens
- DED as a measure of material/structural Health

From the Statement of John B. DeVault to the Subcommittee on Technology and Competitiveness
of the
Committee on Science, Space and Technology
U.S. House of Representatives

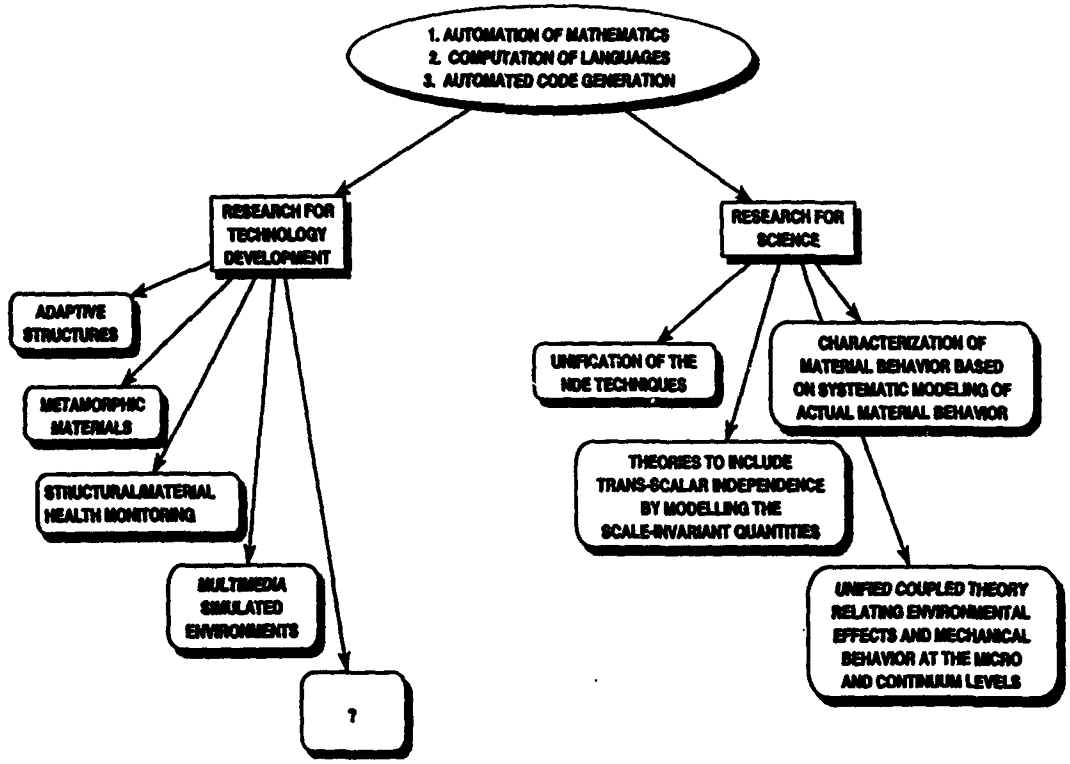
CALL FOR ACTION

- U.S. Advanced Materials Industry Threatened with Extinction
- 20 years Phenomenal Technological Success but Financial Failure
- Engine that Powered Success - DoD - Has Stalled
- America Is World Class at Developing New Technologies but Fails in World Marketplace in Commercializing
- U.S. Focus on Invention, not Adoption of Advanced Materials Technologies; Emphasis Must Shift, and Key is New and Improved Component Manufacturing Technology

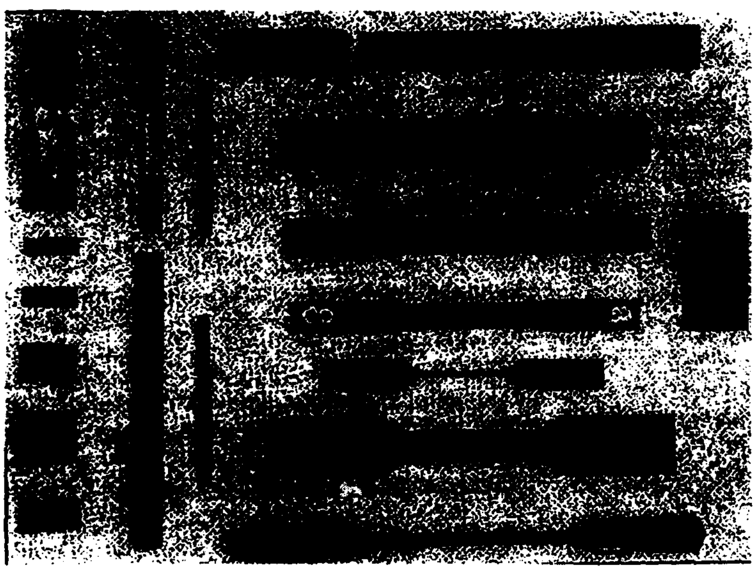
High Cost of Composite Characterization/Certification

- Current Methods Based Upon Metallic Structures Experience/History
  - Extensive coupon, sub-element, element, sub-component, component and full scale testing to obtain experimental data for allowables definition and design verification
  - Material characterization focused on calibration of properties for use in linear elastic design analysis
  - Limited Confidence in analysis results until directly verified by test
- F-22 Program As of Spring 1992
  - Spent $40M on composite characterization
  - Consumed 22,000 pounds of prepreg
  - Tested 15,000 specimens

MEDIA AND KINDS OF RESEARCH



EXAMPLES OF THE WIDE VARIETY OF TEST SPECIMENS EMPLOYED IN COMPOSITE MATERIAL MECHANICAL CHARACTERIZATION:

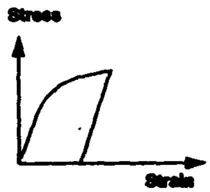


Taken from "Composites Update" Newsletter of University of Delaware.

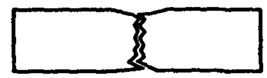
FUNDAMENTAL DIFFERENCE BETWEEN COMPOSITES AND METALS:

ELASTIC | DISSIPATIVE BEHAVIOR | LIMIT CONDITION

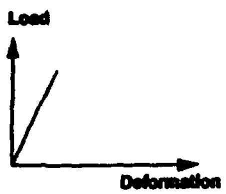
Metals

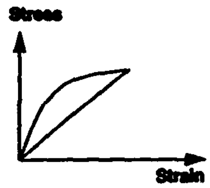


Plastic Flow, Irrecoverable Deformations, Recoverable Elastic Stiffness



Composites





Softens due to Development of Crack Networks, Recoverable Deformations, Irrecoverable Elastic Stiffness

OBJECTIVES:

Develop an automated procedure for characterizing the behavior of composite materials and apply it to different structural applications.

- Develop Large Data Base of Mechanical Behavior of Composites using the In Plane Loader (IPL)
- Design and Develop Advanced Structural Response Simulator Facility
- Demonstrate the Use of this Facility in Materials Selection, Structural Design, and Damage Assessment for Composite Structures

GENERAL APPROACH

A total phenomenological scientific observation of facts using principles of continuum mechanics and applied mathematics that isolates the influence of geometry from observed facts and yields the pure material response over the entire domain of mechanical loads.

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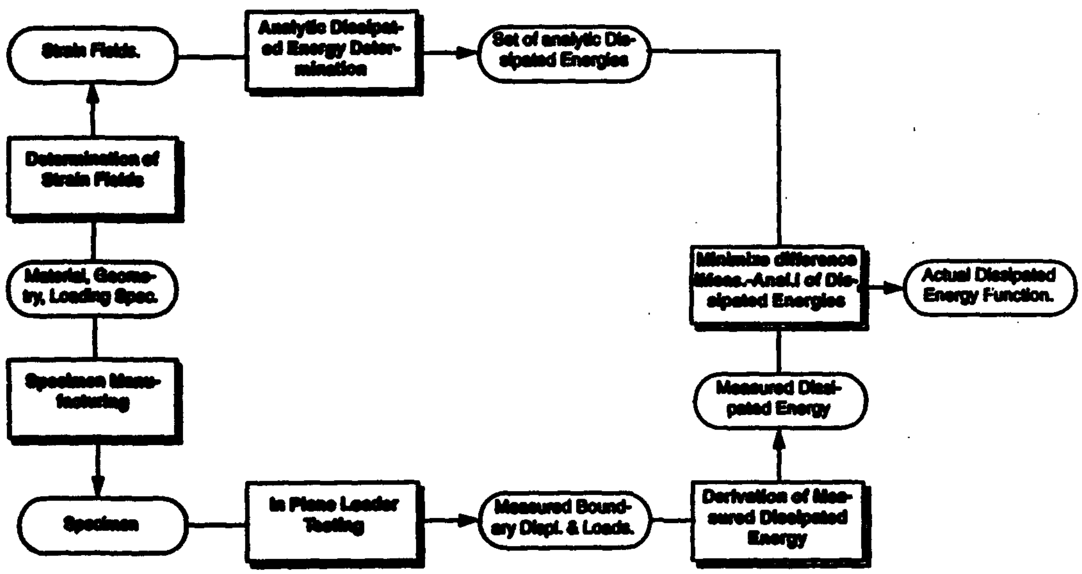
ASSUMPTIONS

- The material of the considered structure is an organic matrix composite.
- The *structural* loading rates lie within a range over which the dissipated energy function for the material is deemed constant for a given loading level.
- The material can be regarded as a mechanically equivalent homogeneous anisotropic.
- Loading is either static or slowly varying in accordance with the considerations already discussed.

ASSUMPTIONS (continued)

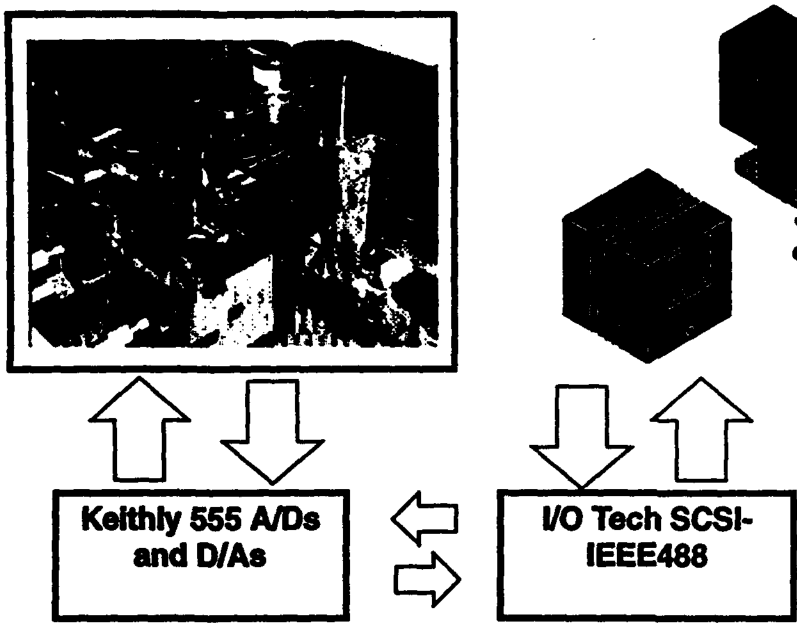
- The material behavior can be represented as $\sigma = \varsigma(\xi,\varepsilon)$. This assumption, utilizes a work potential (energy per unit volume), $\psi(\varepsilon)$, that can be defined as $\sigma = \mathrm{grad}_{\varepsilon}\psi(\xi,\varepsilon)$.
- The total energy absorbed by the material during loading can be regarded as being composed of the sum of a reversible (recoverable) and an irreversible (dissipative) part. The reversible component is the energy which would be recovered if the material were to unload, whereas the irreversible part represents the energy which is dissipated by the internal damage mechanisms. The later can be described by a dissipation density function $\phi(\varepsilon)$ (dissipation energy per unit volume).

DETERMINATION OF DISSIPATED ENERGY DENSITY

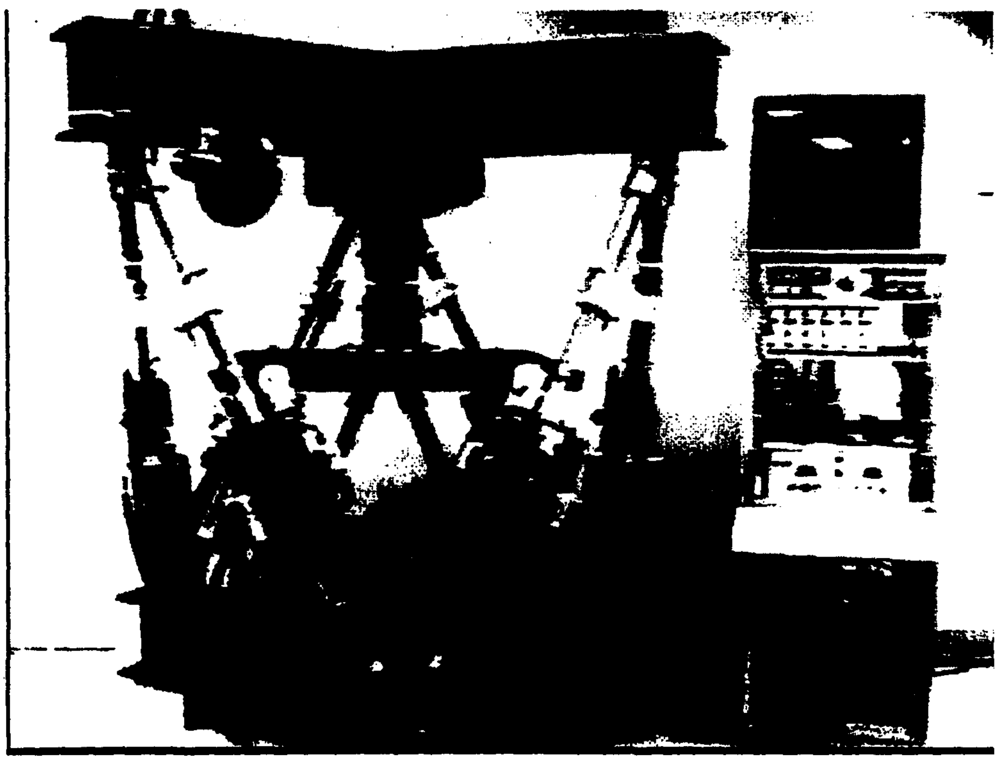


EXPERIMENTAL MATERIAL SYSTEM IDENTIFICATION

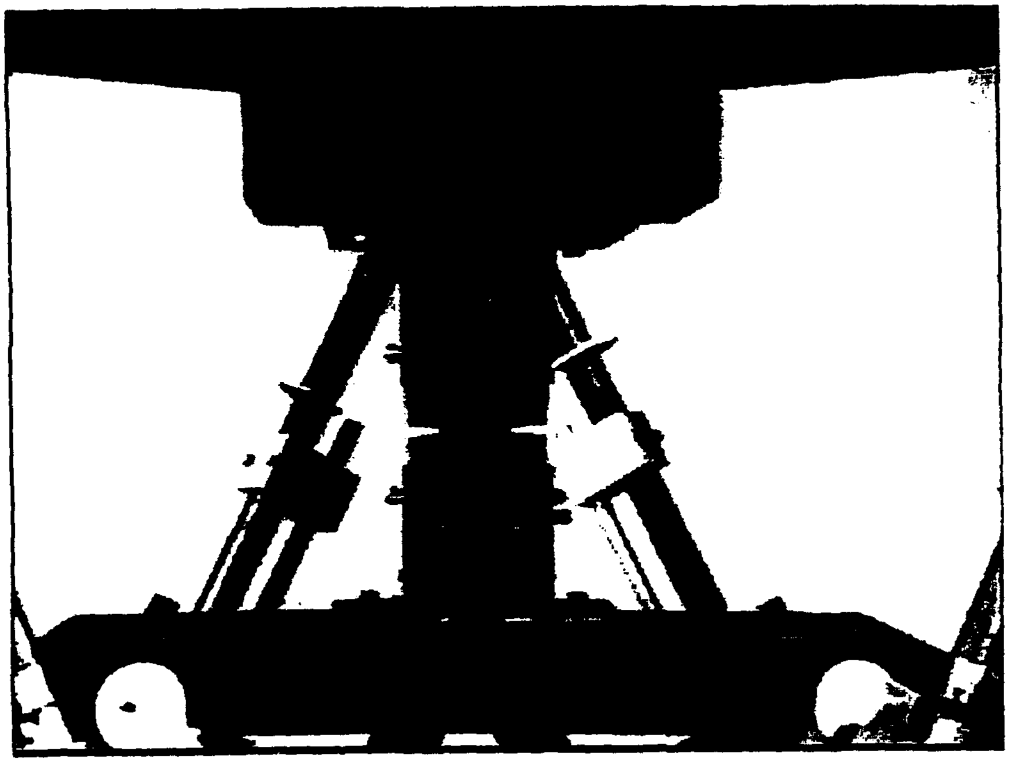
In-Plane-Loader setup:

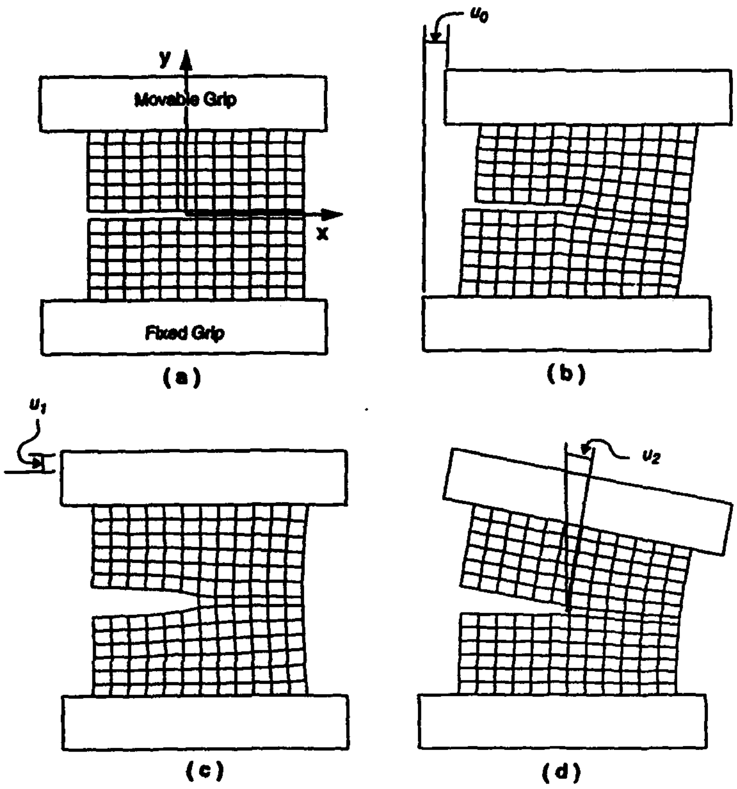


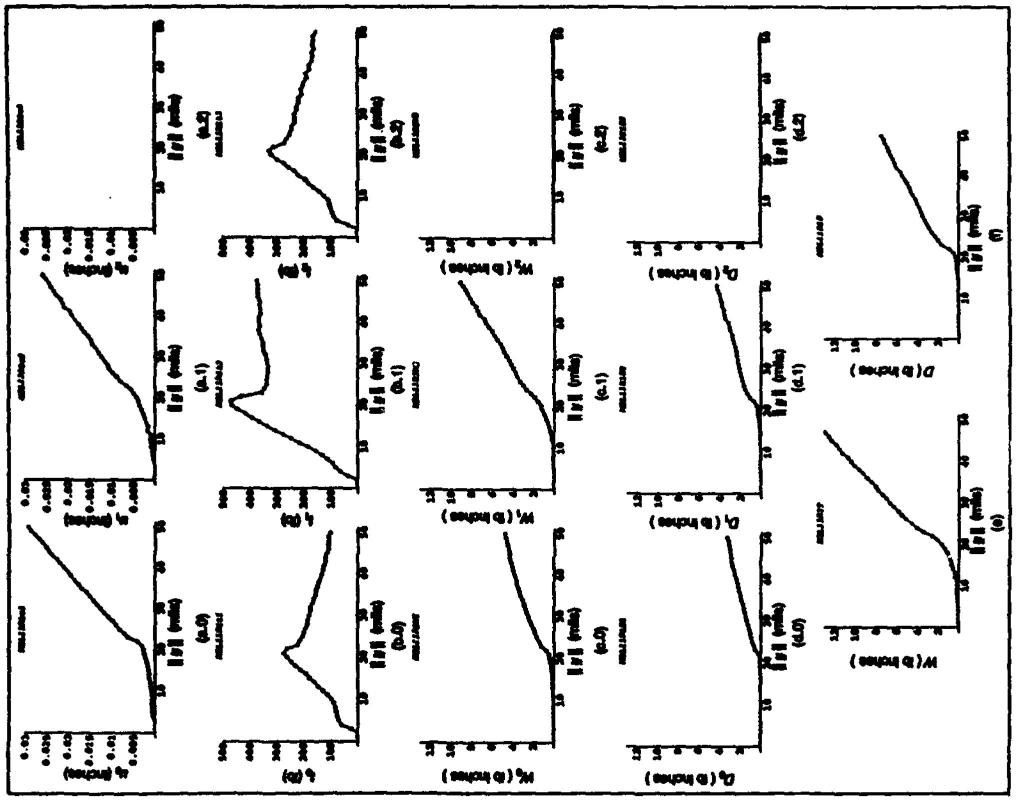
6-D-LOADER SETUP: (under construction)



6-D-LOADER SETUP: (under construction)

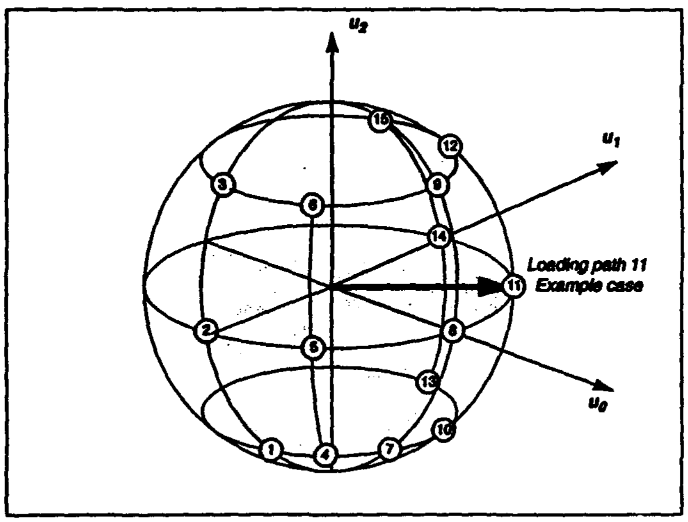






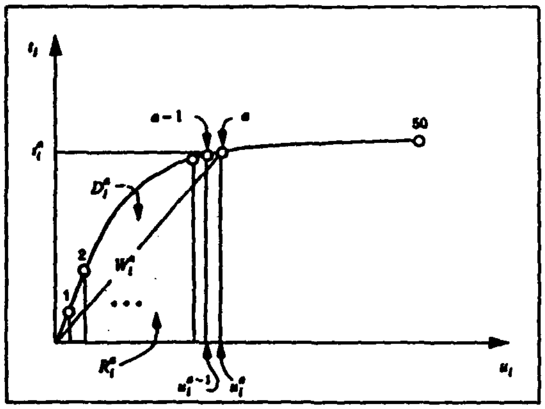
EXPERIMENTAL MATERIAL SYSTEM IDENTIFICATION

Loading Path Definitions



EXPERIMENTAL MATERIAL SYSTEM IDENTIFICATION

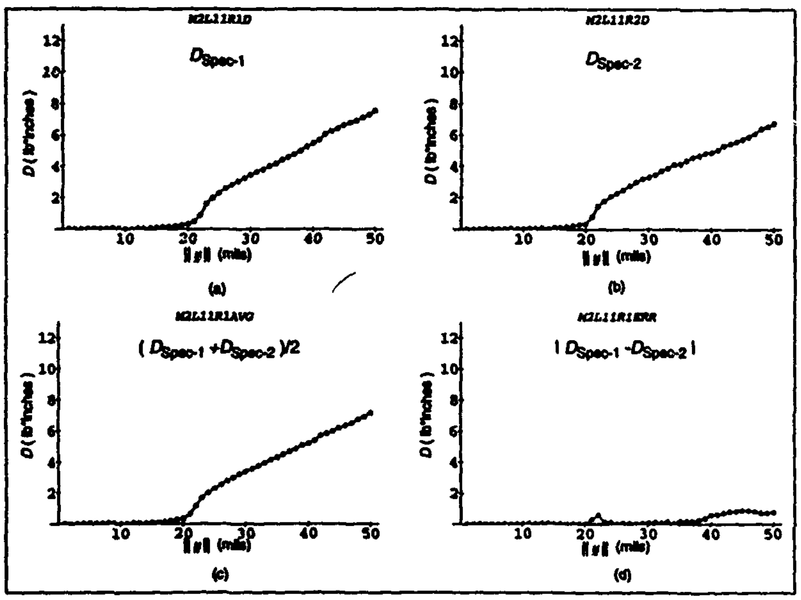
Computation of Specimen Dissipated Energy



$$D^p = \frac{1}{2}\sum_{i=0}^{2}\sum_{a=1}^{p}(f_i^a + f_i^{a-1})(u_i^a - u_i^{a-1}) - \sum_{i=0}^{2}\frac{1}{2}f_i^p u_i^p, \quad \text{for } p = 1, 2, \ldots, 50$$

EXPERIMENTAL MATERIAL SYSTEM IDENTIFICATION

Dissipated Energy Reproducibility



METHODOLOGY

Computation of Dissipated Energy Function

Composition Behavior:

(Total Energy provided to the system) - (Recoverable Energy) = (Total Dissipated Energy by the system)

$$\int_0^{u_r} t_u q_v \, dq^v - \frac{1}{2} t_s u_t \mu^v = \int_{\partial V} \phi(\varepsilon_i(x_j))\, dx_j$$

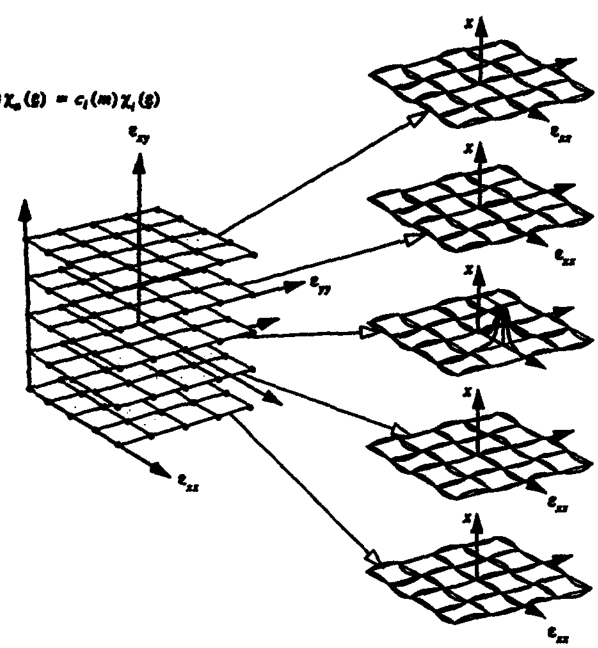
METHODOLOGY

Computation of Dissipated Energy Function

$$\phi(\xi, m) = \phi(\xi, \varsigma) = c_1(m)\chi_1(\xi) + \ldots + c_m(m)\chi_m(\xi) = c_i(m)\chi_i(\xi)$$

$$\Phi = \int_{\Omega} \phi(\xi, \varsigma)\, d\varsigma$$

$$\chi_i(\xi_j) = \left\{ \begin{matrix} 1, & i = j \\ 0, & i \neq j \end{matrix} \right\} \quad \text{for } i, j = 1, 2, \ldots, 125$$



METHODOLOGY

Computation of Dissipated Energy Function

$$\Phi = \int_{\partial_0} (c_1(m)\chi_1(\xi(l_0, z)) + \ldots + c_m(m)\chi_m(\xi(l_0, z)))\,dz = \int_{\partial_0} c_i(m)\chi_i(\xi(l_0, z))\,dz$$

$$\Phi(z_0, l_0) + e = D(z_0, l_0)$$

$$\sum_{e=1}^{100} c_i \chi_i(\xi^p_e) V^p_e + e^p = D^p$$

$$[X]c + e = d$$

$$\chi_{ip} = \sum_{e=1}^{100} \chi_i(\xi^p_e) V^p_e$$

$$d^T = \left[[D^p_1]^T, [D^p_2]^T, \ldots, [D^p_l]^T, \ldots, [D^p_{15}]^T \right], \text{ with } p = 1, 4, \ldots, 49$$

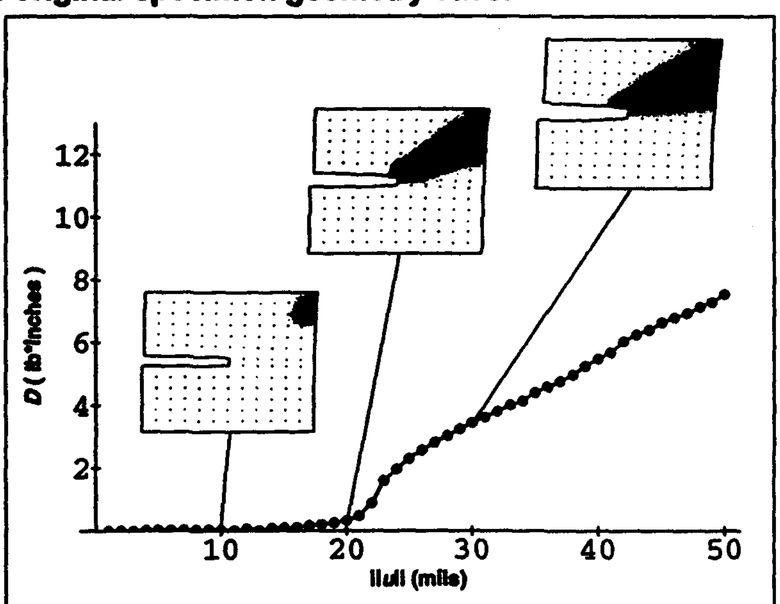
$$[D^p_l]^T = [D^1_l, D^4_l, D^7_l, \ldots, D^{49}_l]$$

$$[M]c \geq 0$$

$$[M] = \begin{bmatrix} M^T_1 \\ M^T_2 \\ \vdots \\ M^T_{100} \end{bmatrix}$$

METHODOLOGY

On original specimen geometry case:



Dissipated Energy a Unique Measure of:

- Non-Linear Constitutive Response
- Local Material Softening due to Damage
- Structural Response (Damaged or Undamaged)

Material Health is the complementary of Dissipated Energy:

- The better the health of the material the lower the value of Dissipated Energy

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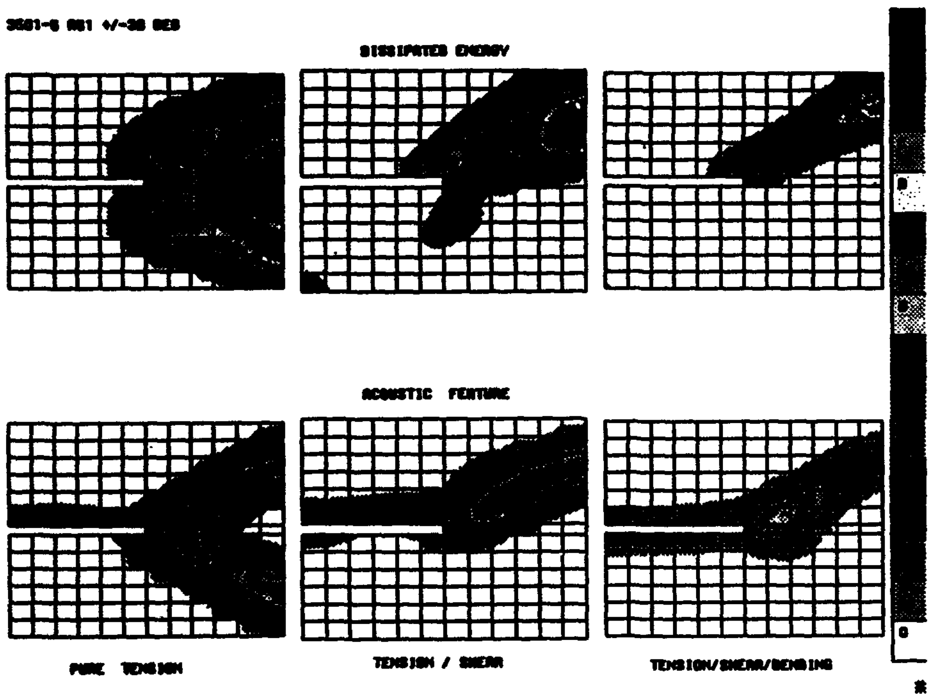
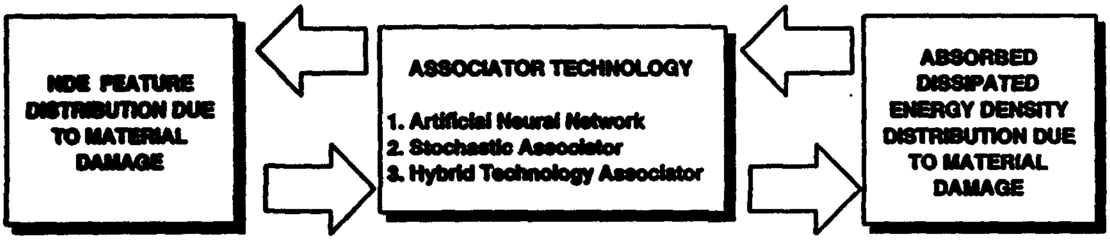
MATERIAL HEALTH FROM DISSIPATED ENERGY

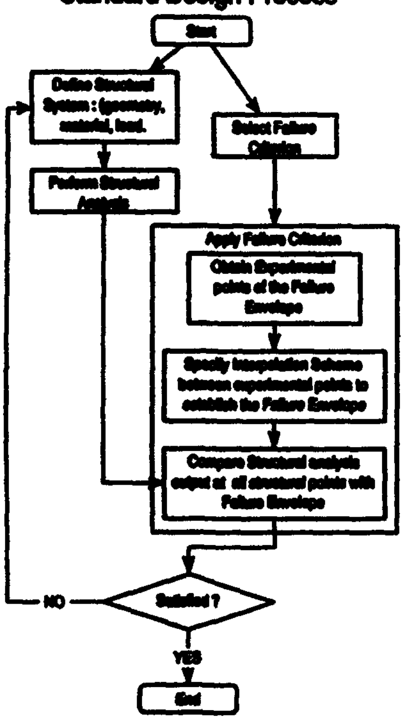


MATERIAL HEALTH MONITORING

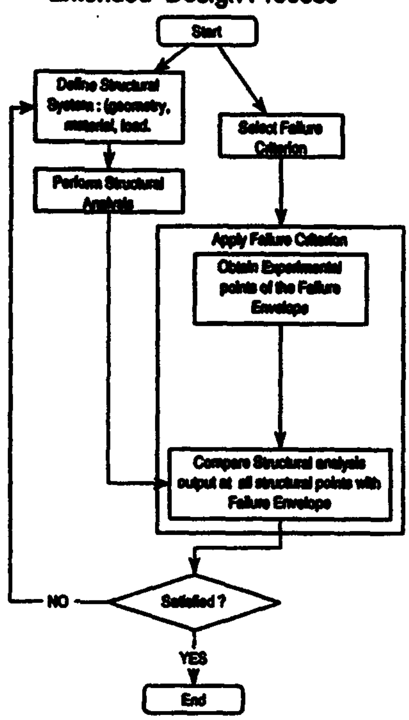


DESIGN PROCESS

Standard Design Process

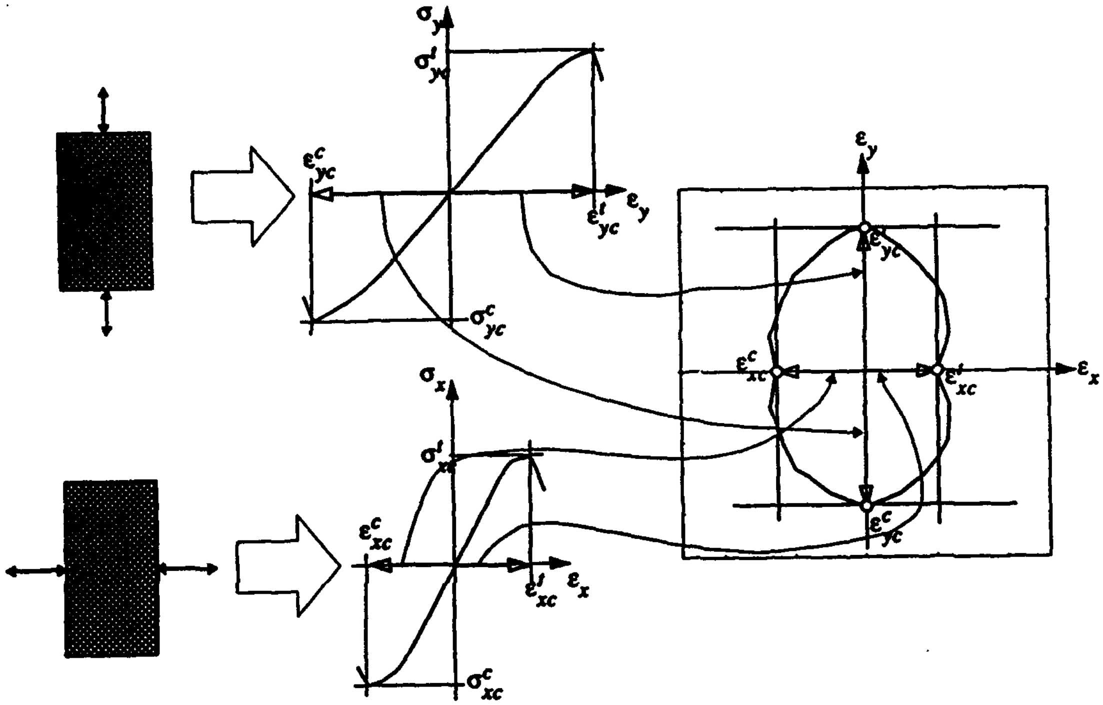


Extended Design Process



EXPERIMENTS RELATED TO FAILURE

Material Failure Criteria



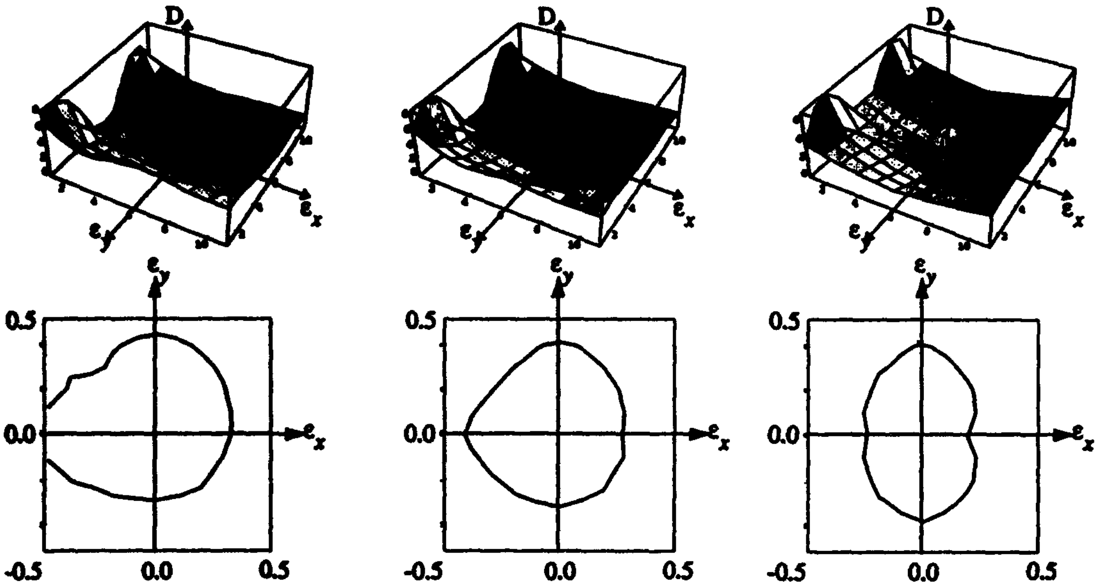
DESIGN PROCESS

Mechanical behavior in the presence of internal damage in terms of overall nonlinear structural response is an extension of the "Failure" concept.

MATERIAL BEHAVIOR

Missile case : Critical DED = 1.0 lb*in/in^3

DED Distributions and Failure Envelopes



61.5 %(+/- 17°) 38.5 %(90°) — 58.0 %(+- 22°) 42.0 % (90°) — 50.0 %(+- 30°) 50.0 % (90°)

MATERIAL BEHAVIOR

Aircraft case

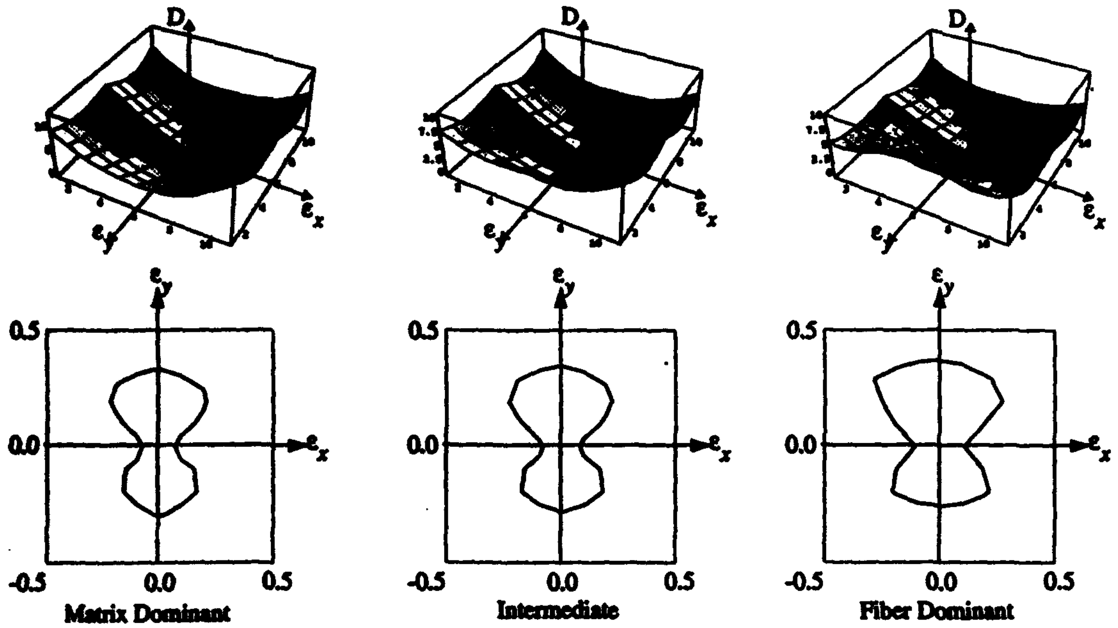
- **Materials: AS4/3501-6**

- Matrix Dominant: 16%(0°)80%(+/- 45°)4%(90°)
- Intermediate: 25%(0°)67%(+/- 45°)8%(90°)
- Fiber Dominant: 48%(0°)48%(+/- 45°)4%(90°)

MATERIAL BEHAVIOR

Aircraft case : Critical DED = 1.0 lb*in/in^3

DED Distributions and Failure Envelopes



Need for Simulation Capability:

To utilize a generalized our generalized material database effectively one needs an automated anvironment in the form of a simulator.

Simulator's Function:

- To automate the transformation of knowledge of the nonlinear response of small composite test specimens to that of full scale structures.
- To provide the appropriate facilities for "what-if" studies related to design objectives.
- To provide the automated capability to easily perform complex parametric studies.
- To provide customization flexibility by allowing user controlled or self adaptive modification in order to enhance user friendliness and general capability.

Simulator's Components:

- Material constitutive behavior data base
- Solid modeling and image rendering module
- Structural analysis pre- and post- structural analysis processing module
- Universal interface to structural analysis codes
- User interface with symbolic processing and knowledge acquisition capabilities.

EXAMPLE SIMULATIONS

Plate with Hole(s) and Bolted Joints

- Comparison of Tension/Compression behavior
- Effect of material orientation

Iosipescu Specimen

- Effect of load magnitude variation
- Effect of Notch angle variation

EXAMPLE SIMULATIONS

All materials: AS4/3501-6

Tension/Compression Specimen with Hole & Bolted Joints:

- Fiber Dominant: 48%(0^o)48%(+/- 45^o)4%(90^o)
- Matrix Dominant: 16%(0^o)80%(+/- 45^o)4%(90^o)
- Intermediate: 25%(0^o)67%(+/- 45^o)8%(90^o)

Iosipescu:

- Quasi Isotropic: 25%(0^o)50%(+/- 45^o)25%(90^o)

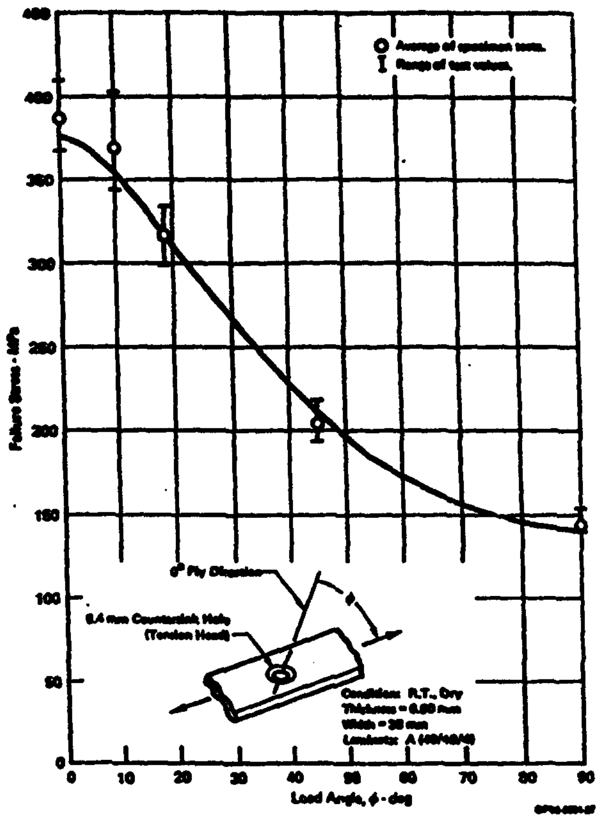
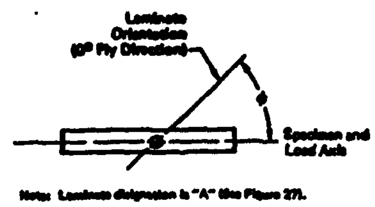


Figure 28. Tension Strength vs Load Angle

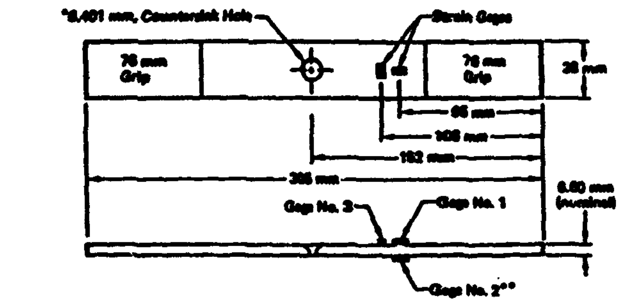
Laminate Orientation Relative to Specimen Axis



Angle ϕ (deg)	Number of Specimens	
	Tension	Compression
0	5	4
10	5	5
16.5	5	2
45	5	5
90	5	5

Note: Laminate designation is "A" (See Figure 27).

Specimen Configuration



*ST3M426V4 bolt installed "finger tight" (AN960C416 washers and NAS679A4W nut)
**Gage no. 2 on compression specimens only

Figure 28. Coupon Specimens for Variable Off-Axis Angle Loading

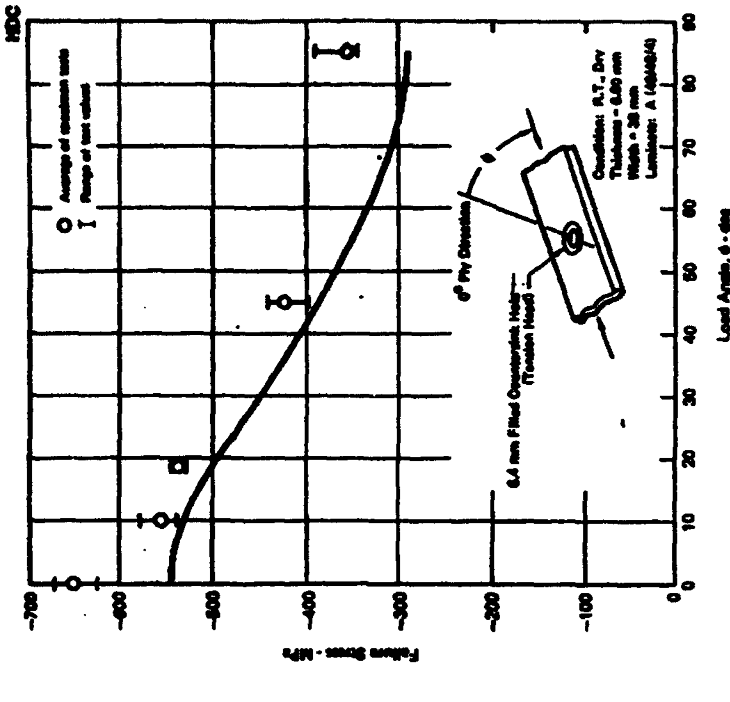


Figure 28. Compression Strength vs Load Angle

The second series of off axis testing evaluates the validity of the failure prediction methods for four additional laminates. These laminates (designated B, C, D and E) are loaded 18.5° off the 0° ply axes. The test specimen is shown in Figure 30, and the laminates are defined in Figure 27. A summary of test results including laminate A is presented in Figure 31. Predicted failure stresses agree very well with test results except for laminate B loaded in compression. The only significant difference between laminates A and B is that laminate B has no 90° plies and therefore has an angular span of 90° between the ±45° plies without fibers. This indicates that laminates having angular spans greater than 45° without fibers may require a special failure criteria (at least for compression loading). It should also be noted that the laminates with ±22.5° plies tend to fail at stresses below predicted. More test data should be generated for this laminate family before the F/A-18 failure prediction method is considered valid for this type of laminate. F/A-18 laminates utilize the full compliment of 0°, ±45° and 90° plies but do not include ±22.5° plies.

PLATE WITH ONE HOLE

Comparison of Total Dissipated Energy isocontours (2 inch.lb intervals) and MCAIR specimen results

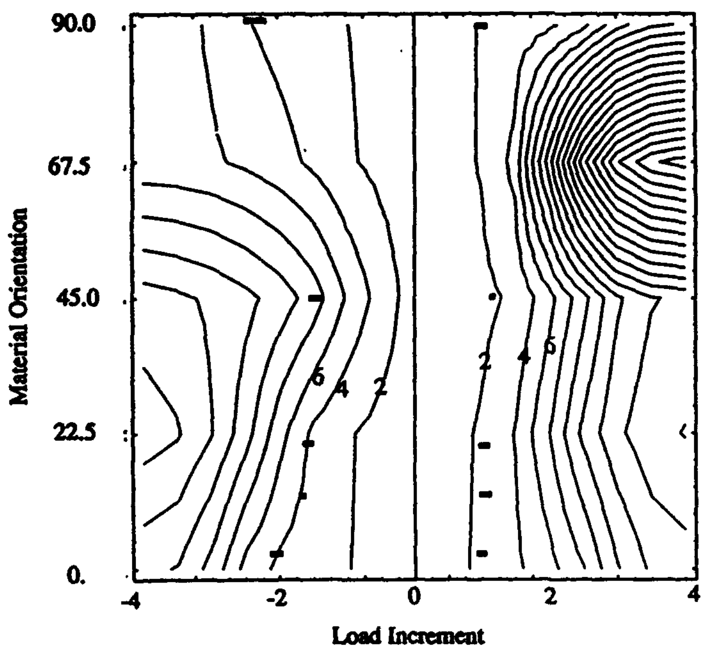
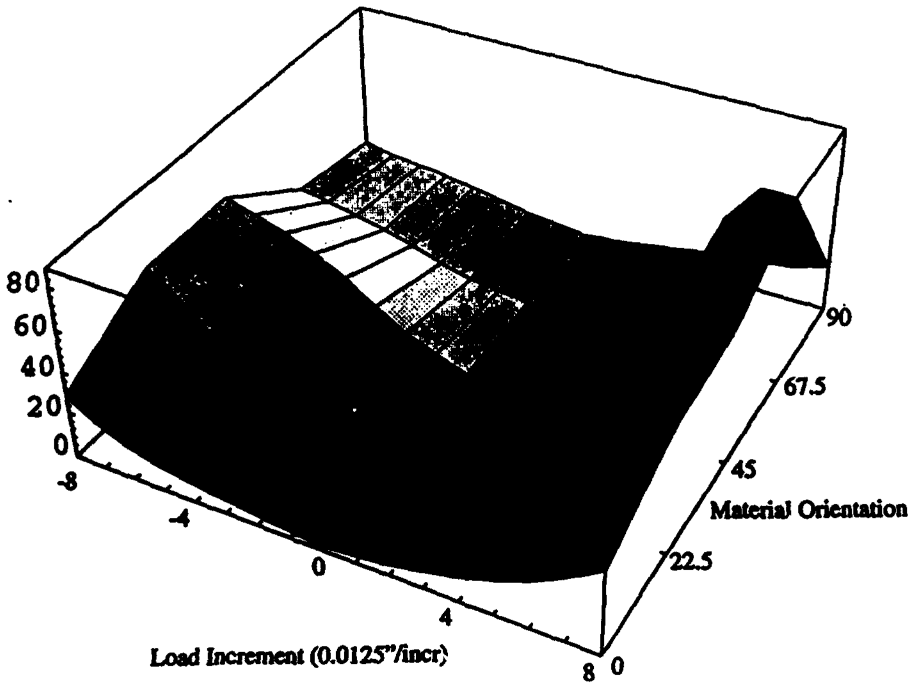
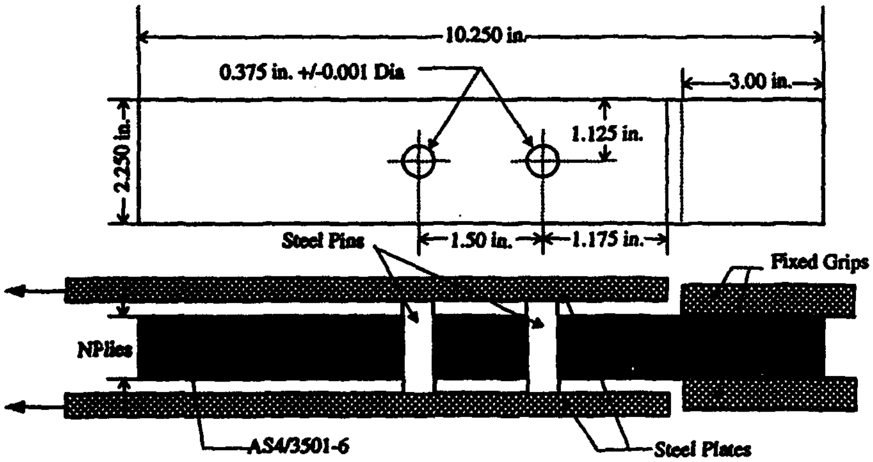


PLATE WITH TWO HOLES

Total Dissipated Energy vs. load increments and material orientations

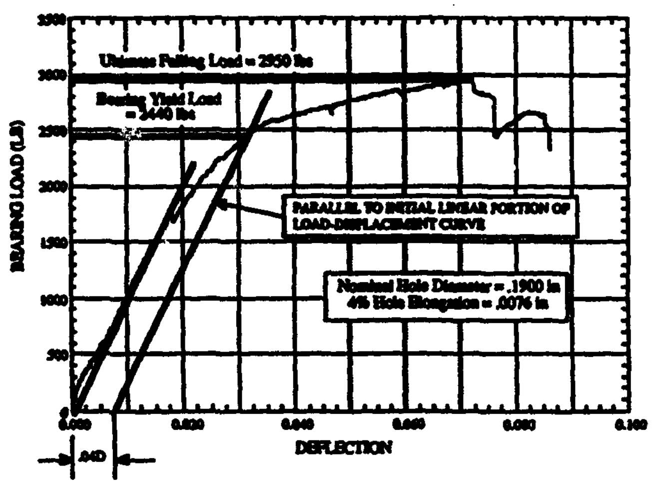


Two-Pin, High Load Transfer Test



Typical Pin Bearing Test

Bearing - Load Versus Deflection



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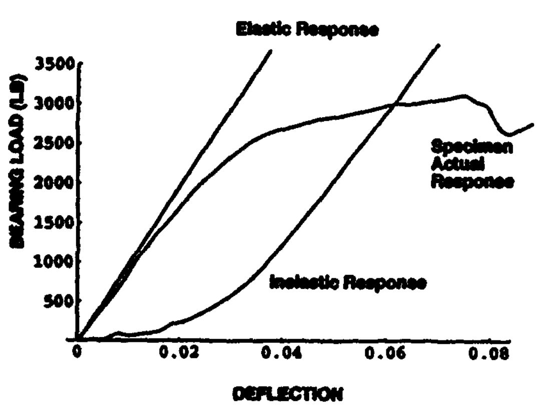
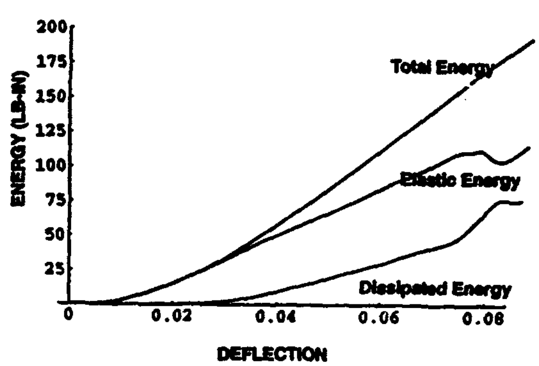
Typical Pin Bearing Test

Elastic - Inelastic Decomposition

Load Deflection Response



Energy Response



SIMULATION OF DAMAGED COMPOSITE MOTOR CASES

HYPOTHESIS I: Dissipated Energy in conjunction with Structural Analysis can predict burst pressure of Gouged Bottles.

HYPOTHESIS II: A Damaged Zone in a Motor Case can be modelled as an equivalent volume of material with reduced stiffness.

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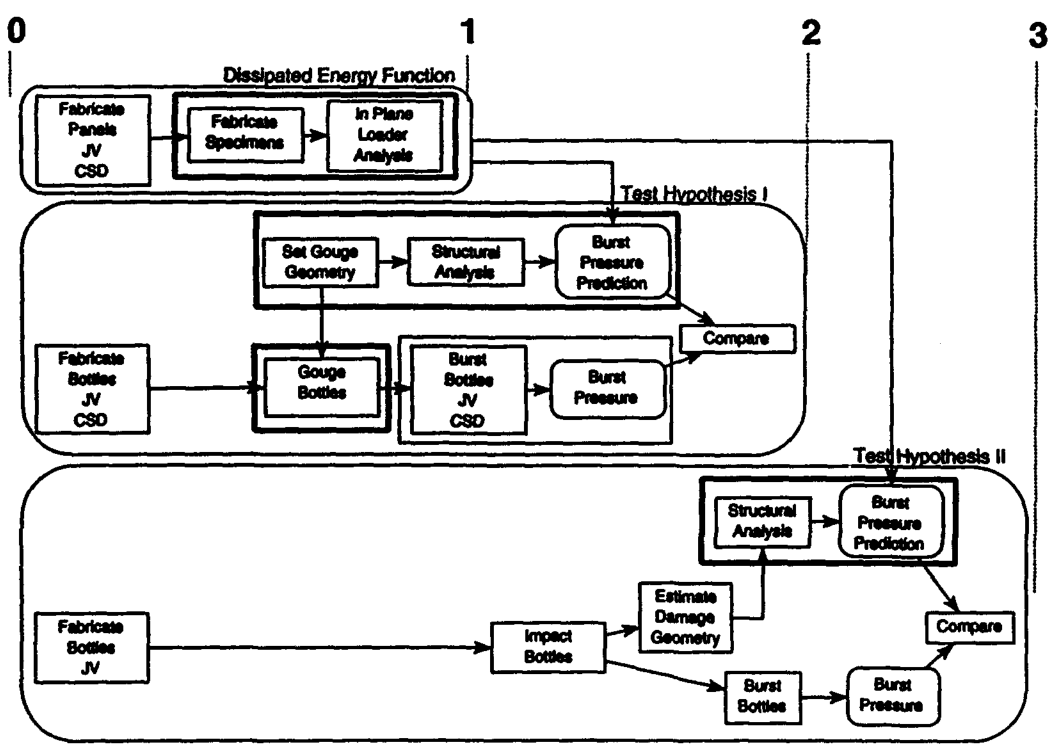


MATERIALS:

Flat Panels

JV: (12"x12"x1/8")

(+/-22°;+/-35°;90°+/-22°) **8 panels each(total of 24)**

CSD: (12"x12"x1/8")

(+/-22°;+/-35°;90°+/-29.5°) **8 panels each(total of 24)**

Bottles

JV: 16 Boottles(20" Diameter)

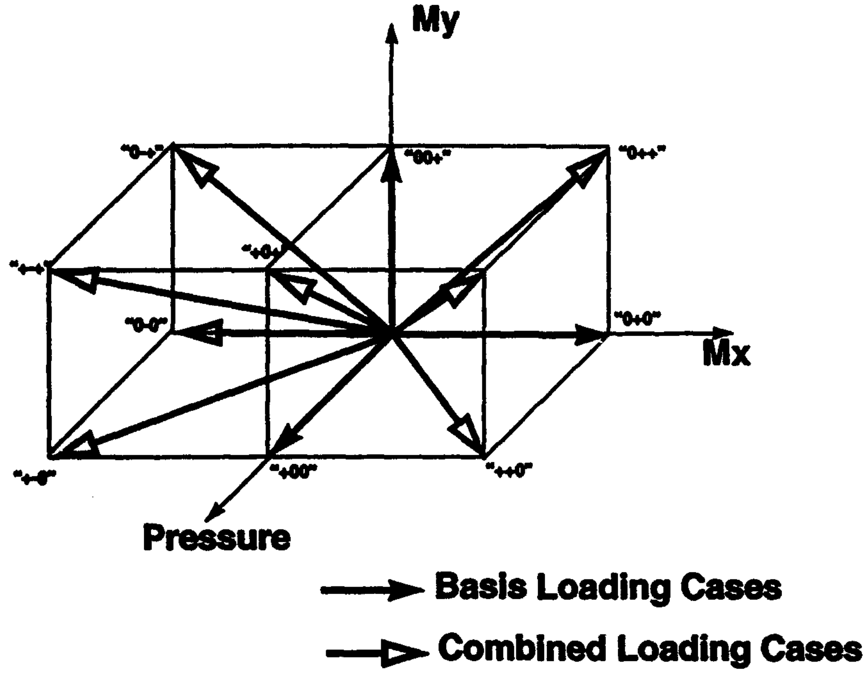
CSD: 15 Bottles (12" Diameter)

SIMULATION OF INTERSECTING CYLINDERS

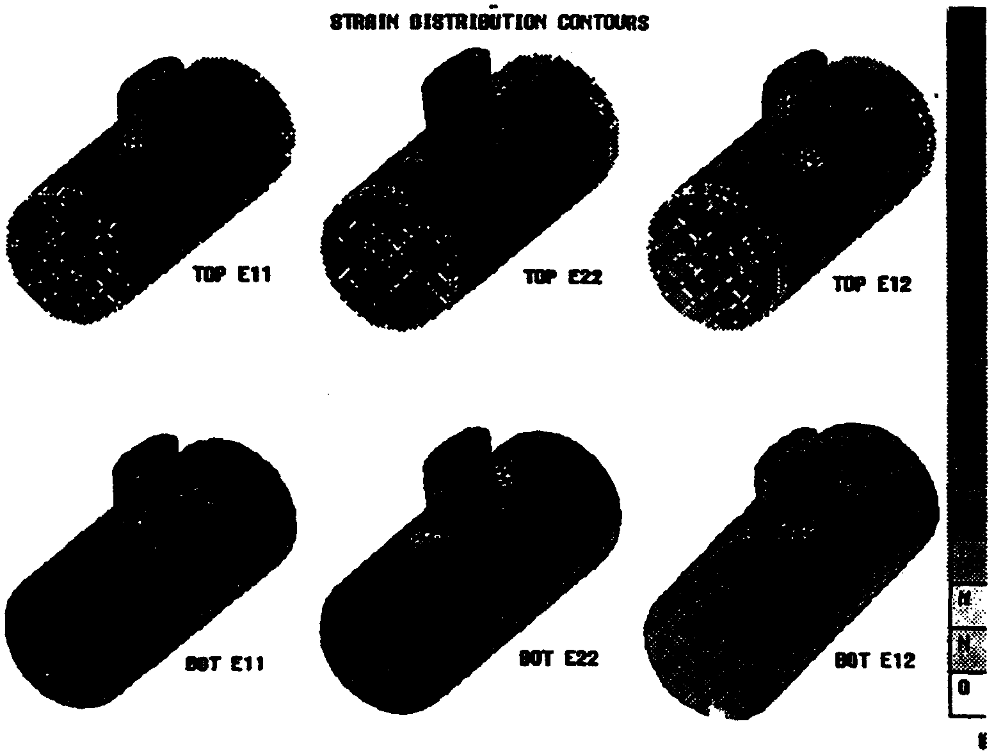
OBJECTIVES:

- Effect of combination of loads
- Effect of different materials
- Use Sensor to monitor the material and structural health of the structure

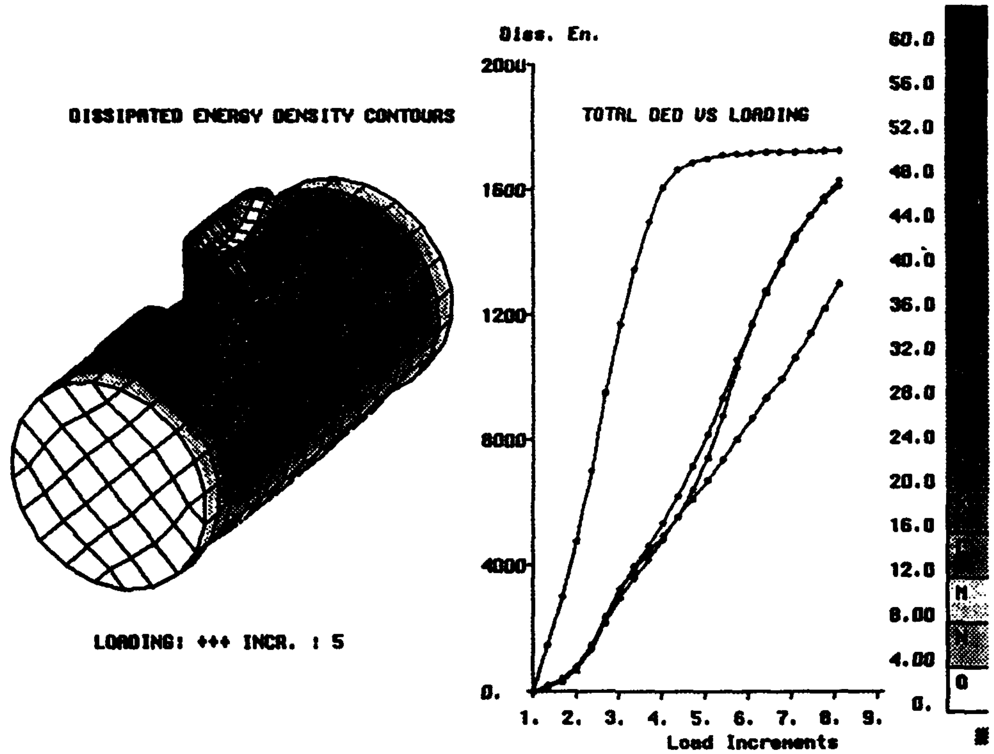
LOADING PATHS SPECIFICATION



STRAIN STATE EVALUATION



STRUCTURE HEALTH FROM DISSIPATED ENERGY



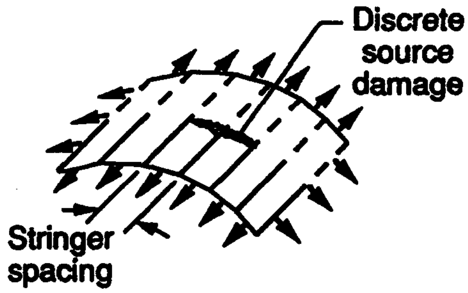
USE OF FRACTURE TOUGHNESS TO DESIGN FOR DISCRETE SOURCE DAMAGE

C. C. POE, JR.
NASA Langley Research Center

MIL-HDBK-17 Guidelines Working Group
March 29-31, 1994
Monterey, CA

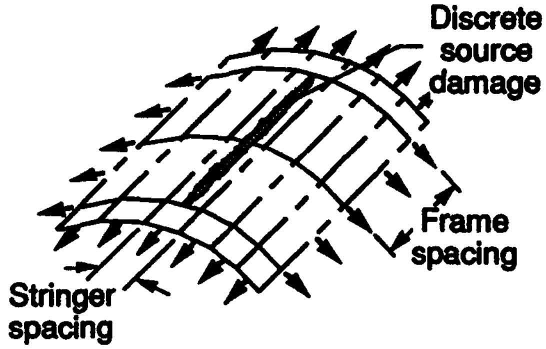
DISCRETE SOURCE DAMAGE CRITERIA

<u>FAR PART 25</u> - Withstand 70% of limit flight maneuver loads and 40% of limit gust velocity each combined with maximum appropriate cabin pressure with discrete source damage (penetrations over two bays of skin, including one stringer or frame).



Sources -

- Impact with a 4-lbm bird.
- Propeller and uncontained fan blade impact.
- Uncontained engine failure.
- Uncontained high energy rotating machinery failure.

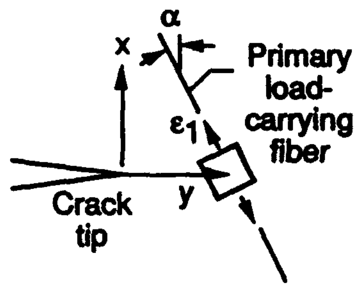


<u>MIL-STD-1530A</u> - Containment of battle damage.

UNIFYING STRAIN CRITERION (LEFM)

From theory of elasticity, the fiber strain ahead of crack is

$$\varepsilon_1 = Q(2\pi y)^{-1/2} + H(O)$$



where

$$Q = K\xi / E_x$$

and

$$\xi = [1-(\nu_{xy}\nu_{yx})^{1/2}][(E_x / E_y)^{1/2} \sin^2\alpha + \cos^2\alpha]$$

At failure,

$$\varepsilon_1 = \varepsilon_{tuf} \text{ at } y = \overline{d_o}$$

Thus,

$$Q_c = \varepsilon_{tuf}(2\pi\overline{d_o})^{1/2}$$

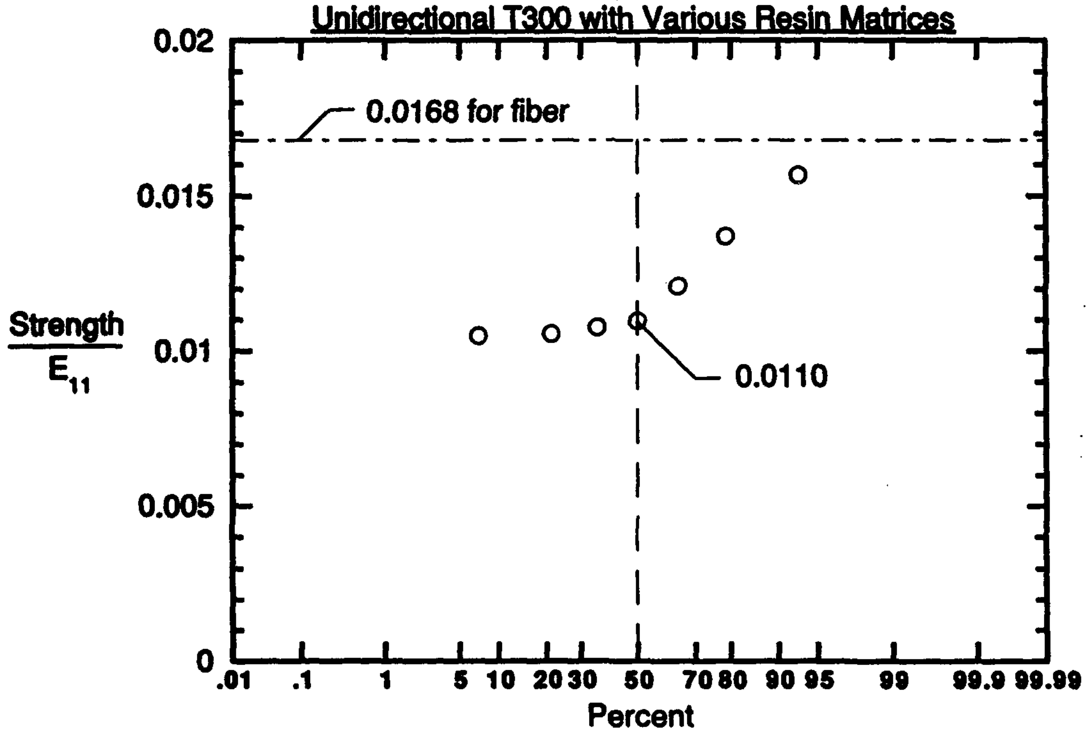
and

$$K_Q = Q_c E_x / \xi$$
$$= (2\pi\overline{d_o})^{1/2}\varepsilon_{tuf} E_x / \xi$$

AJCLA84/LEFM/Strain Criterion

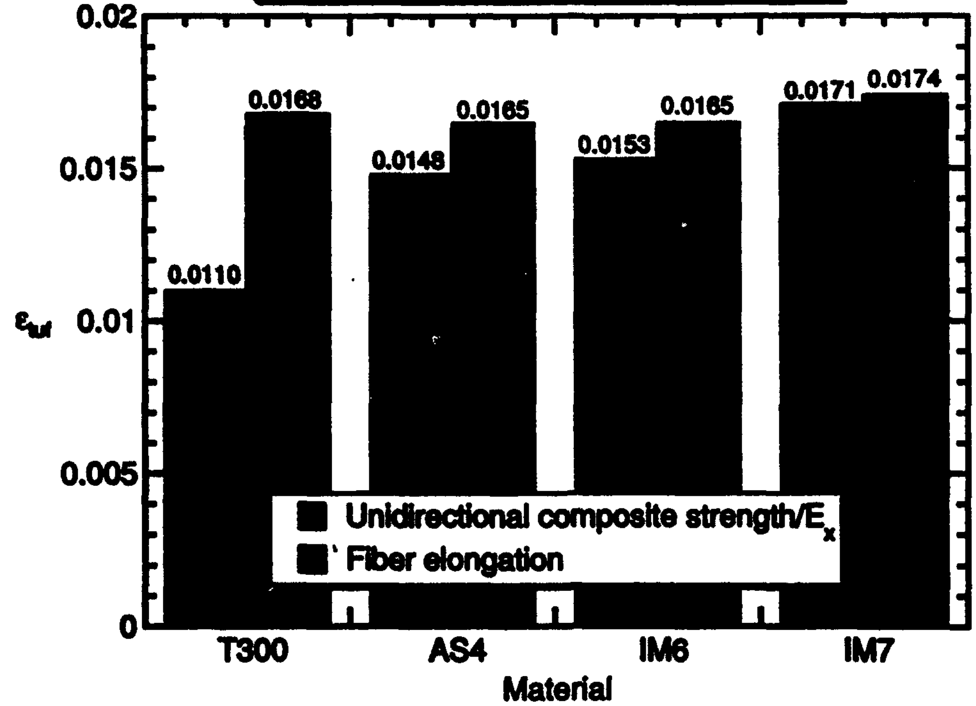
FAILING STRAINS OF COMPOSITES

Unidirectional T300 with Various Resin Matrices



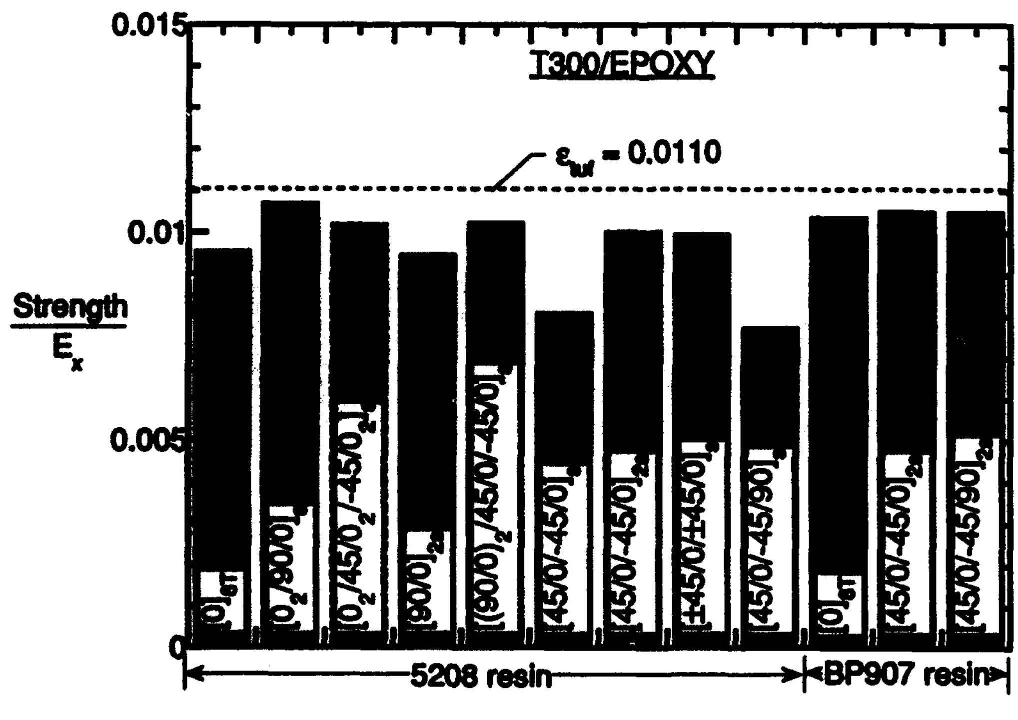
AJCLA84/T300 Strains

FIBER FAILING STRAINS



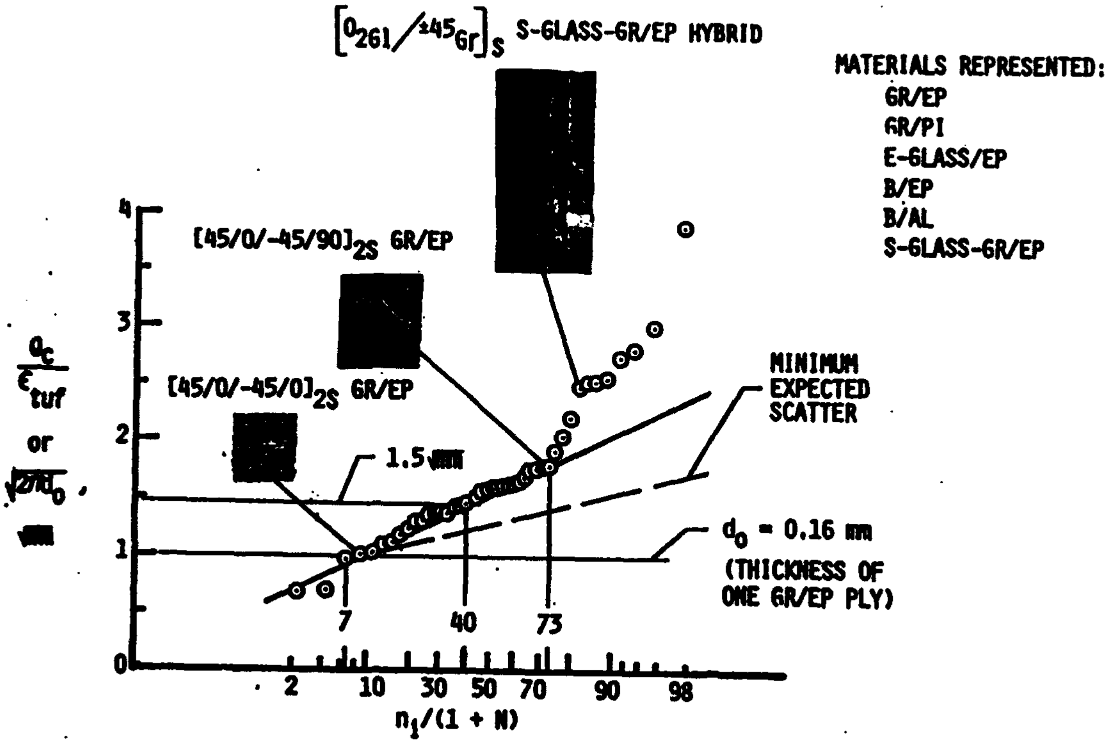
AIOLA94/Fiber Failing Strains

TENSION STRENGTHS OF LAMINATES



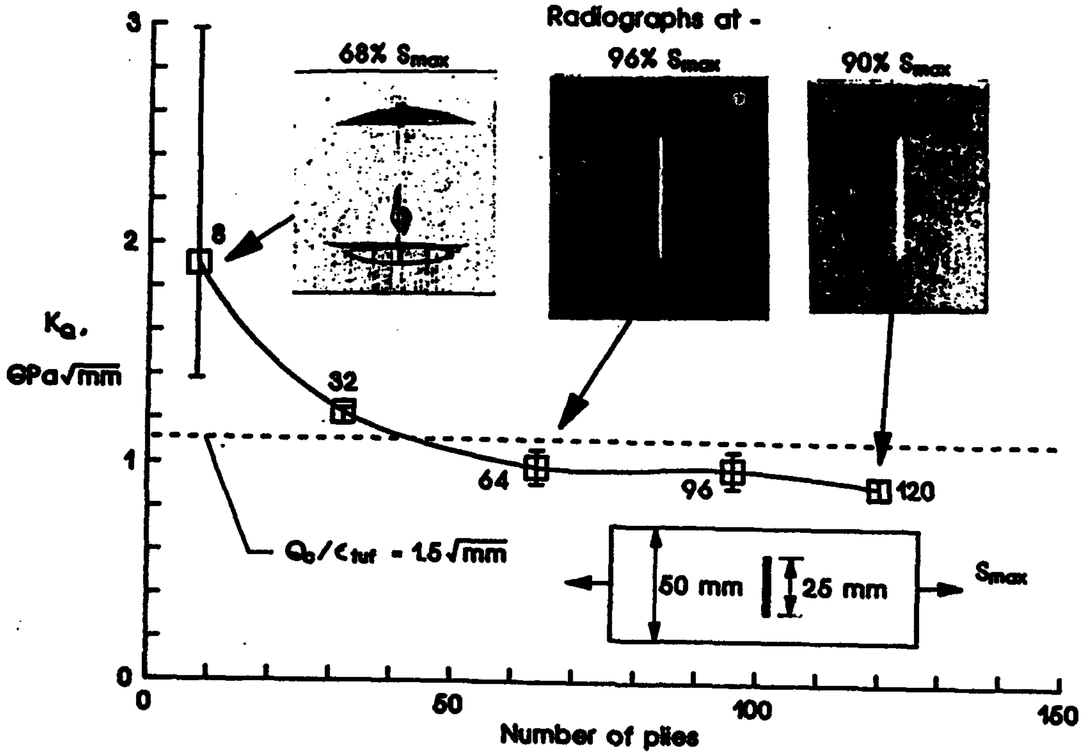
AIOLA94/Strain Criterion (T300)

Q_c/ϵ_{tuf} VALUES FOR $[0_i/\pm45_j/90_k]$ LAMINATES

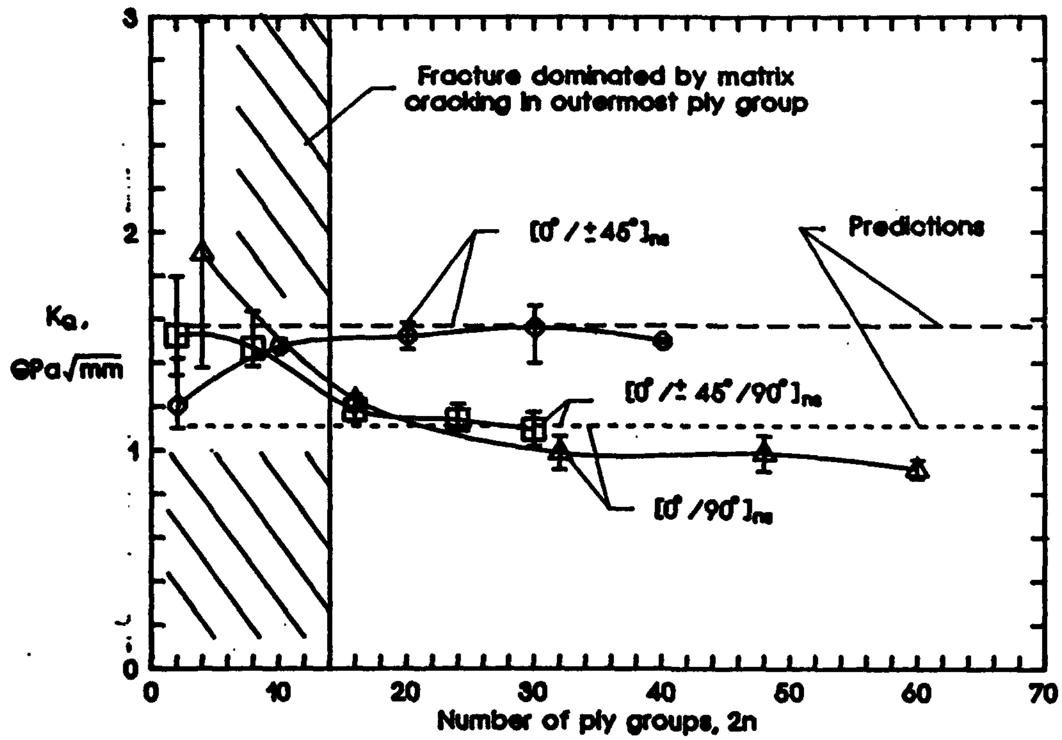


CRACK-TIP DAMAGE VARIES WITH THICKNESS

T300/5208 $[0/90]_{ns}$ GR/EP



FRACTURE TOUGHNESS AND THICKNESS
T300/5208



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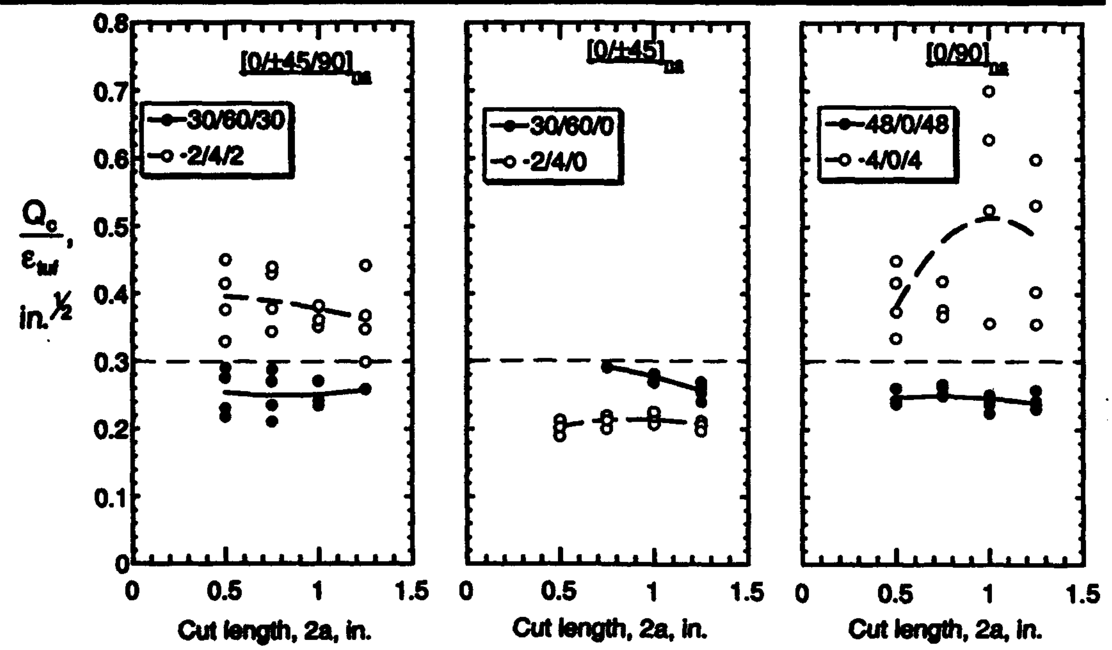
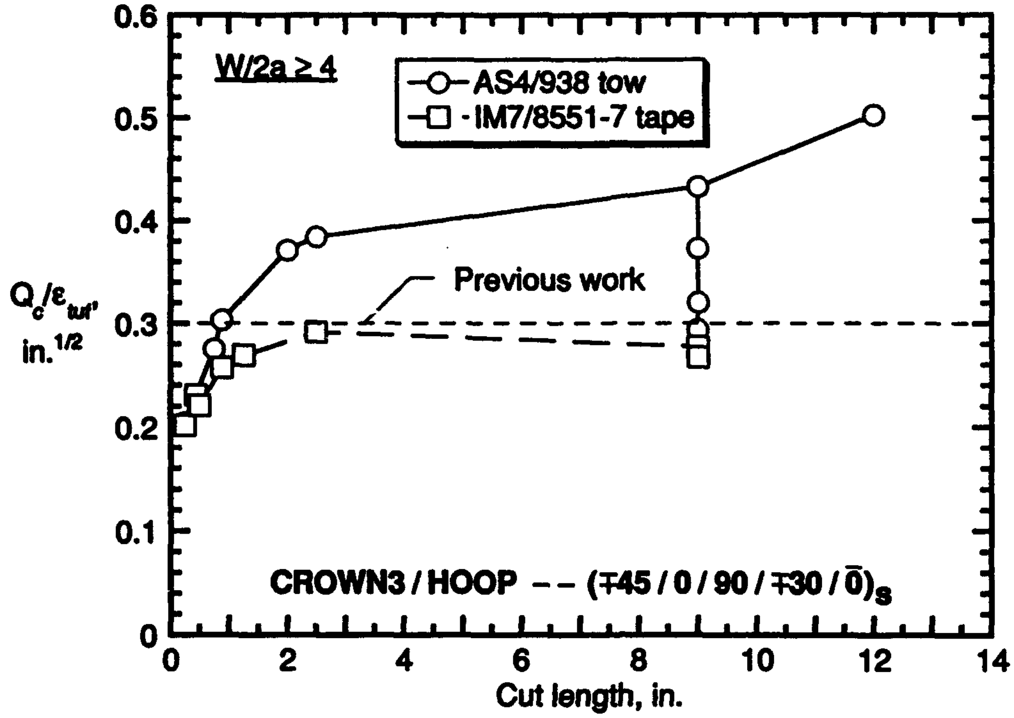
FRACTURE TOUGHNESS OF T300/5208 LAMINATES



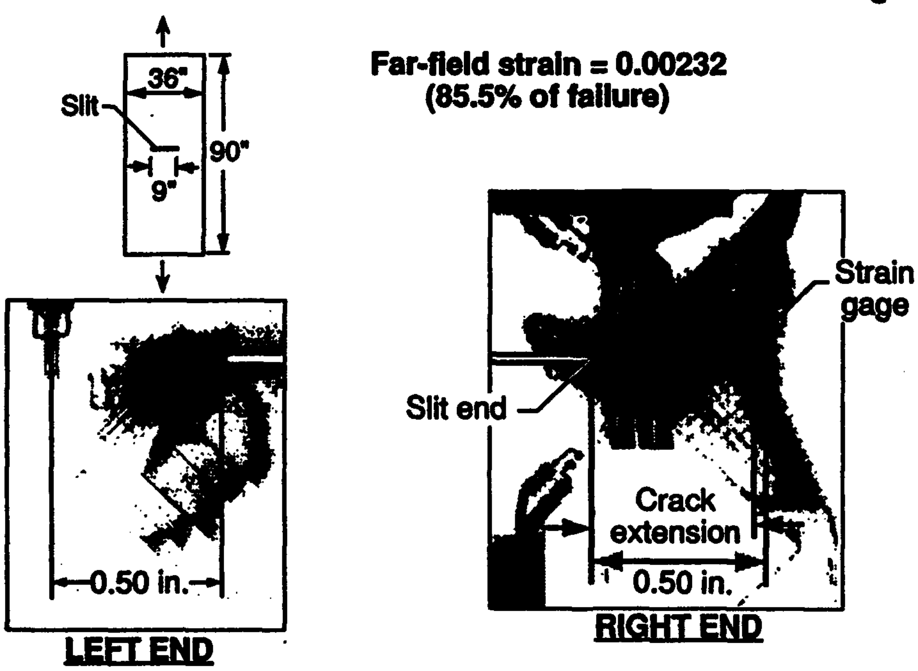
/CROWN/T300 All Qc

FRACTURE TOUGHNESS AND CUT LENGTH

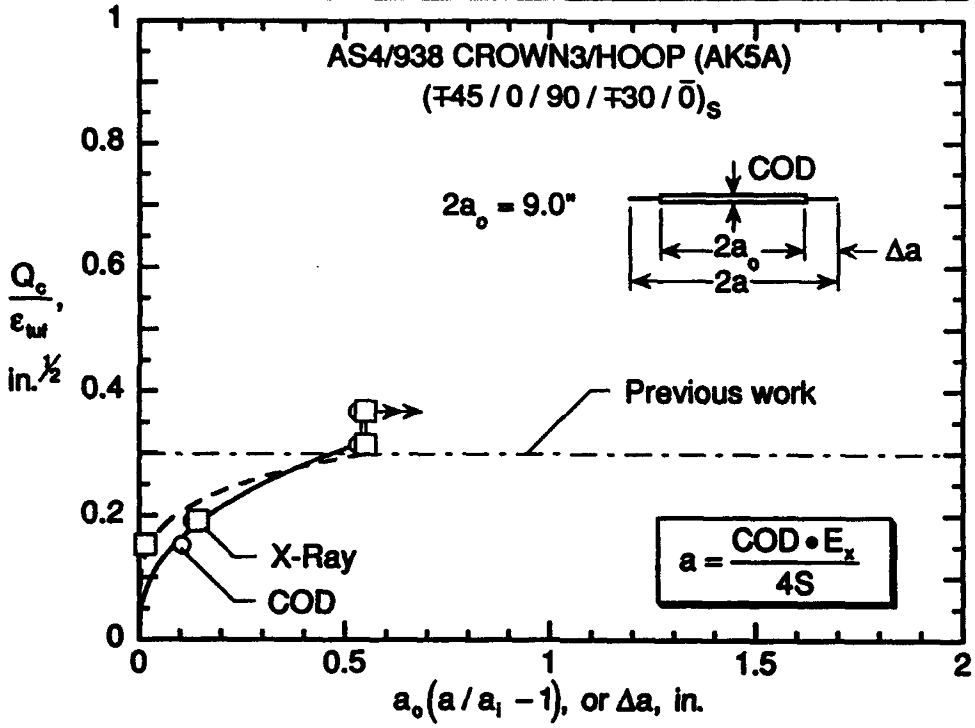


CRACK-TIP DAMAGE IMMEDIATELY BEFORE FAILURE

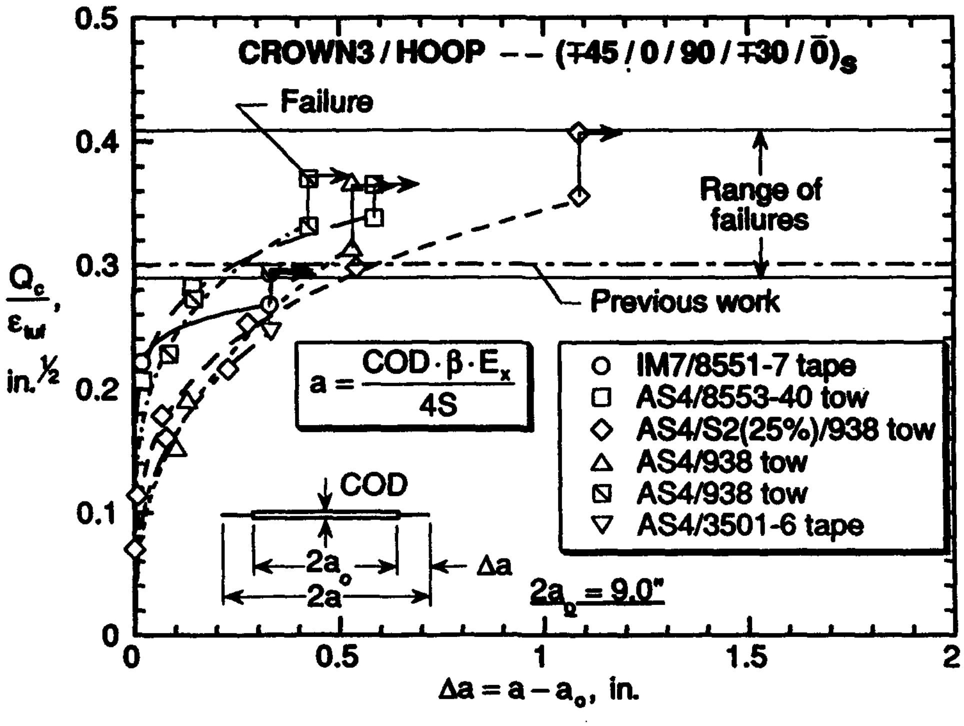
AS4 / 938 CROWN3 / HOOP (AK5A) -- $(\mp45/0/90/\mp30/\bar{0})_s$



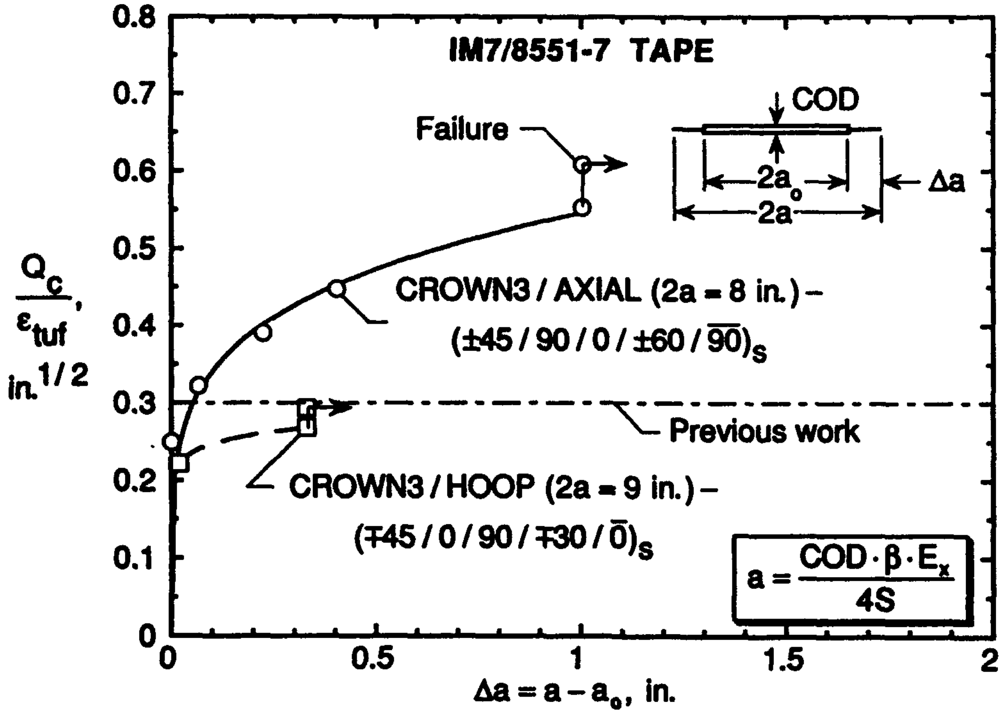
FRACTURE TOUGHNESS & CRACK GROWTH



FRACTURE TOUGHNESS & CRACK GROWTH

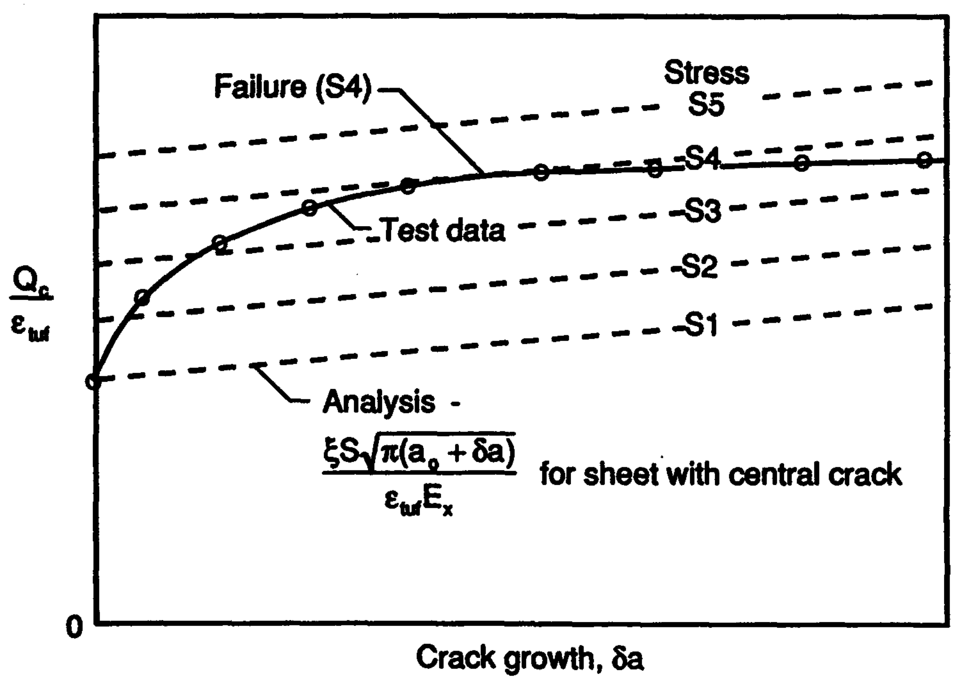


FRACTURE TOUGHNESS & CRACK GROWTH



/CROWN/COD-Spec.152

CRACK GROWTH RESISTANCE METHOD

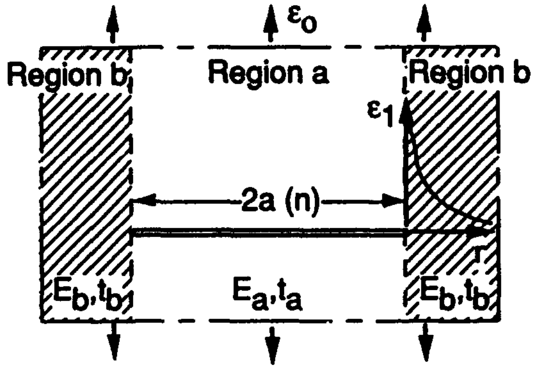


/ACT94/Resist Method

SHEET WITH CRACK AND BUFFER STRIPS

Region *b* represents buffer strip. From a shear-lag analysis, the strain in first intact fiber in Region b is approximately

$$\varepsilon_1 = \frac{\zeta^{1/2}\, 2^{2n}(n+1)!\, n!\, \varepsilon_o}{(2n+1)!}$$



where $\zeta = (E\,t)_a/(E\,t)_b$; and, for a large number of cut fibers *n*,

$$\varepsilon_1 = \tfrac{1}{2}\varepsilon_o\sqrt{\pi\zeta n}$$

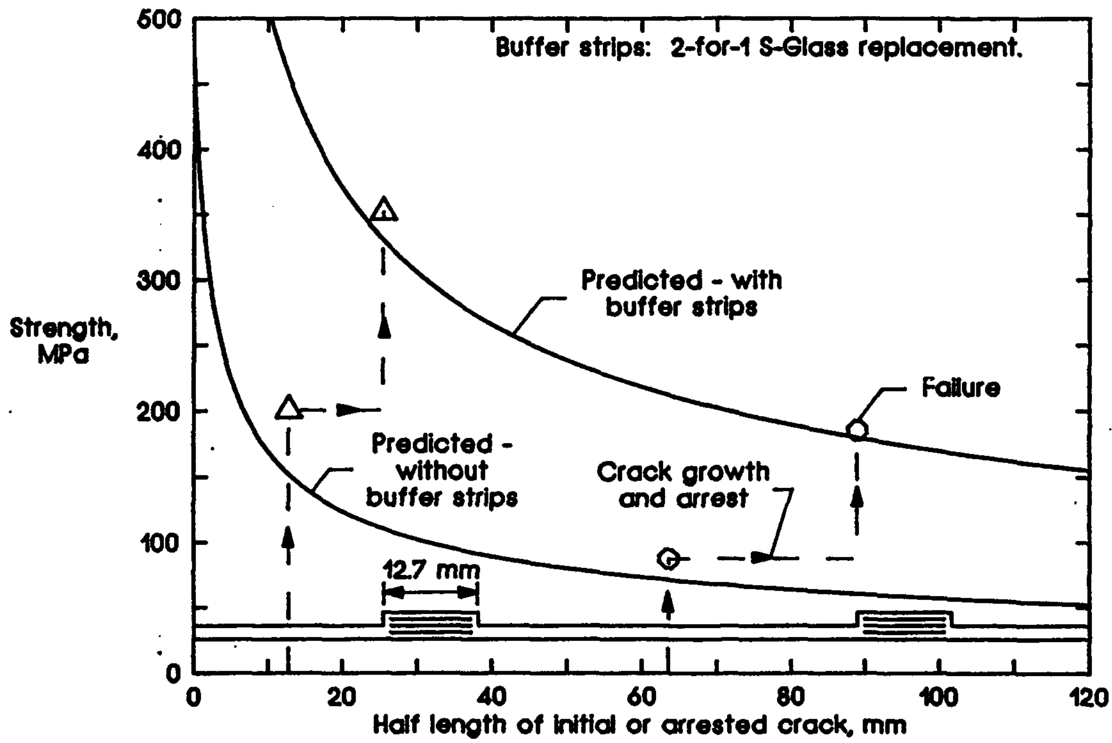
For an orthotropic continuum with regions *a* and *b*, assume that

$$\varepsilon_1 = \bar{Q}\,(2\pi r)^{-1/2} + H(0)$$

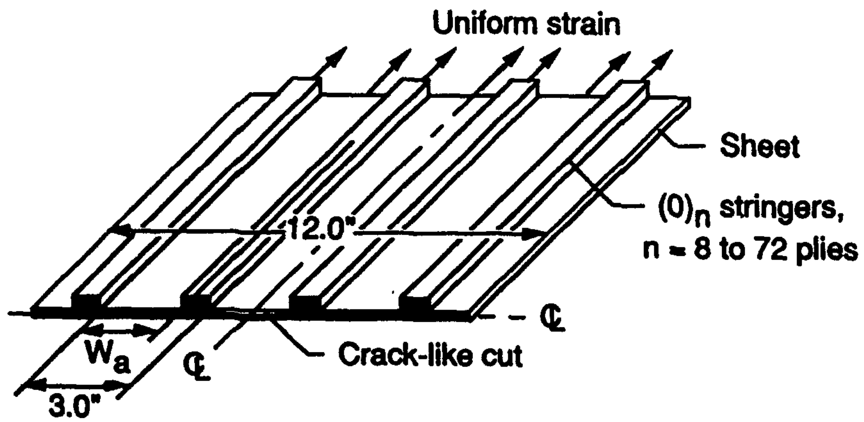
where $\bar{Q} = \xi\,\bar{K}/E_x$ and $\bar{K} = E_x\,\varepsilon_o\sqrt{\pi a \zeta}$ for infinite sheet with uniaxial applied stress. Take notice that the finite width of the buffer strip is not taken into account here.

RESIDUAL STRENGTHS

T300/5208 [45/0/-45/90]$_{2s}$ PANELS WITH S-GLASS STRIPS



CONFIGURATION OF STIFFENED PANELS



Material: T300/5208
Sheet layups: $[45/0/-45/90]_{2s}$
and
$[45/0/-45/0]_{2s}$

Wa, in.	$\mu = \frac{\text{Stringer stiffness}}{\text{Panel stiffness}}$
2.0	0.3
1.0 2.0 2.5	.5
2.0	.7

/UCLA94/Config. Stiff. Panels

SHEET WITH CRACK AND STRAPS

Regions *a* and *b* represents sheet and straps, respectively. Recall that

$$\varepsilon_1 = \bar{Q}\,(2\pi r)^{-1/2} + H(0)$$

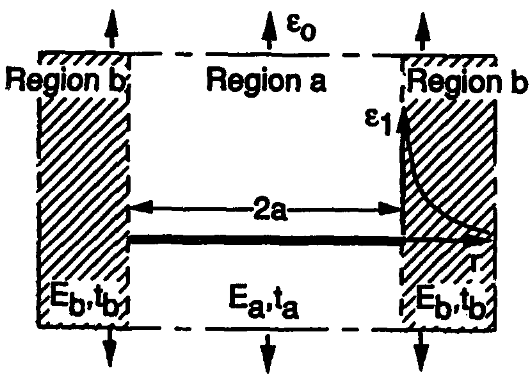
where

$$\bar{Q} = \xi\,\bar{K}/E_x,$$

$$\bar{K} = E_x\,\varepsilon_o\sqrt{\pi a \zeta}$$

for infinite sheet with uniaxial applied stress, and

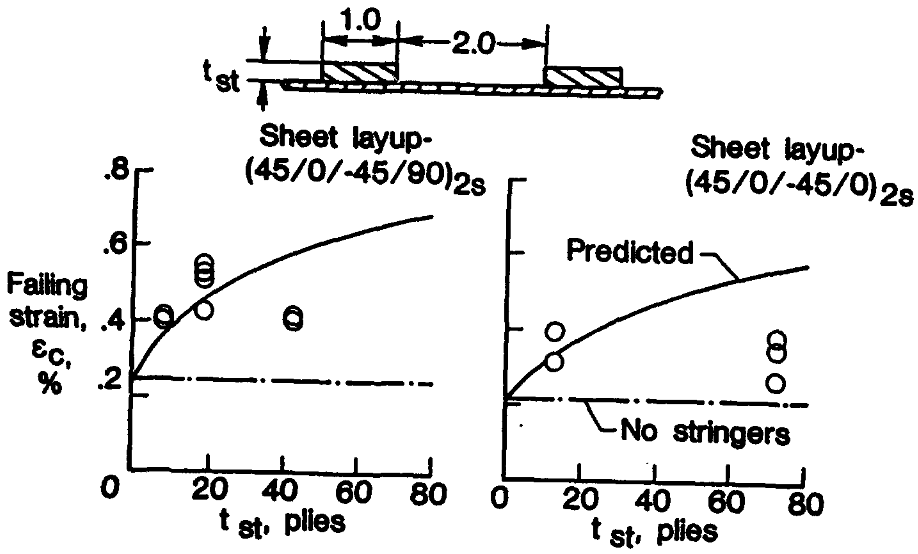
$$\zeta = (E\,t)_a/(E\,t)_b.$$



Because the sheet and straps are in parallel, $(Et)_b = (Et)_a + (Et)_{st}$ where the subscript *st* refers to the straps. Take notice that the finite width of the buffer strip is not taken into account here.

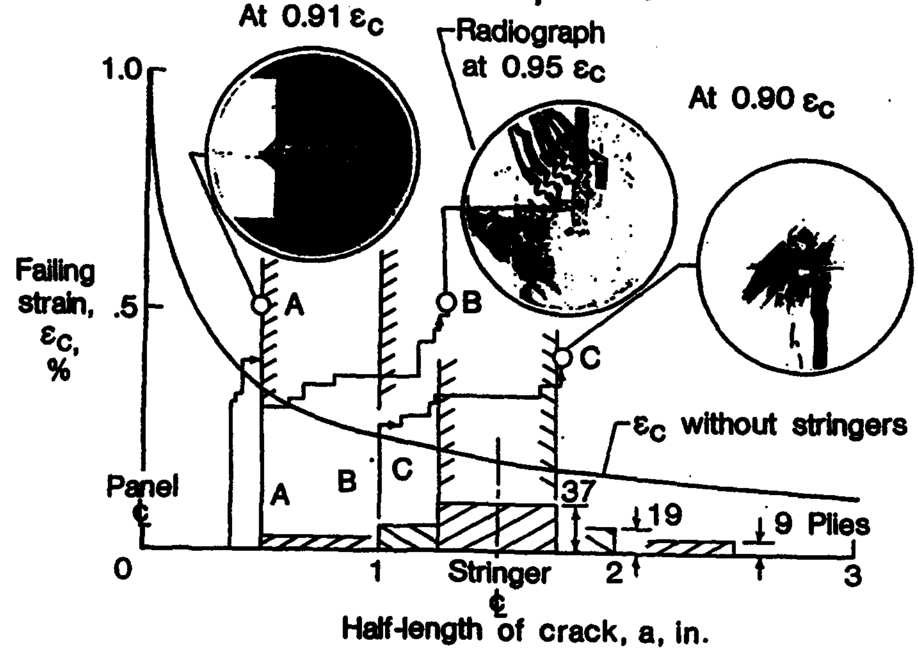
/ACT94Q for Straps

FAILING STRAIN VERSUS STRINGER THICKNESS



NASA L-6170-9 C. POE 8/13-16/84

TEST RESULTS FOR $(45/0/-45/90)_{2S}$ PANELS WITH $\mu = 0.5$



LIMITED EFFECTIVENESS OF STRAPS

Bending and delamination increase with increasing strap thickness. Let

$$\alpha = (E\,t)_{st}/(E\,t)_a$$
$$= \zeta^{-1} - 1$$

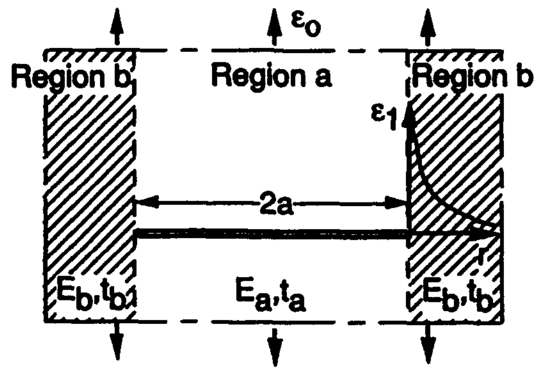
Reduce effectiveness of straps for bending and delaminations by replacing α by $\alpha\, e^{-\gamma\alpha}$, resulting in

$$\zeta = (1 + \alpha\, e^{-\gamma\alpha})^{-1}$$

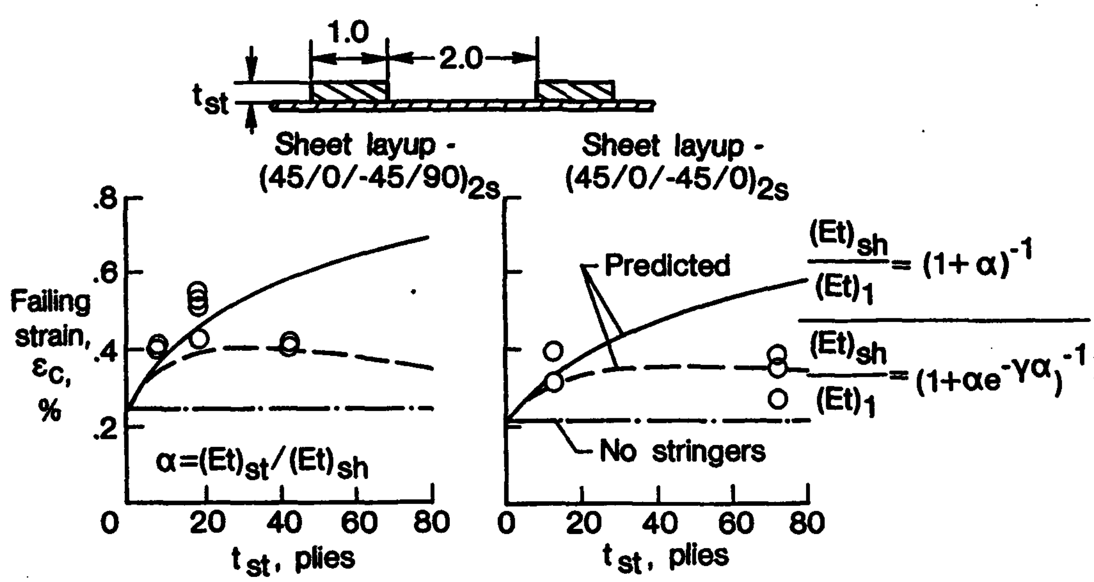
The minimum value of ζ occurs when $\alpha = 1/\gamma$, resulting in

$$\zeta_{min} = [1 + (\gamma e)^{-1}]^{-1}$$

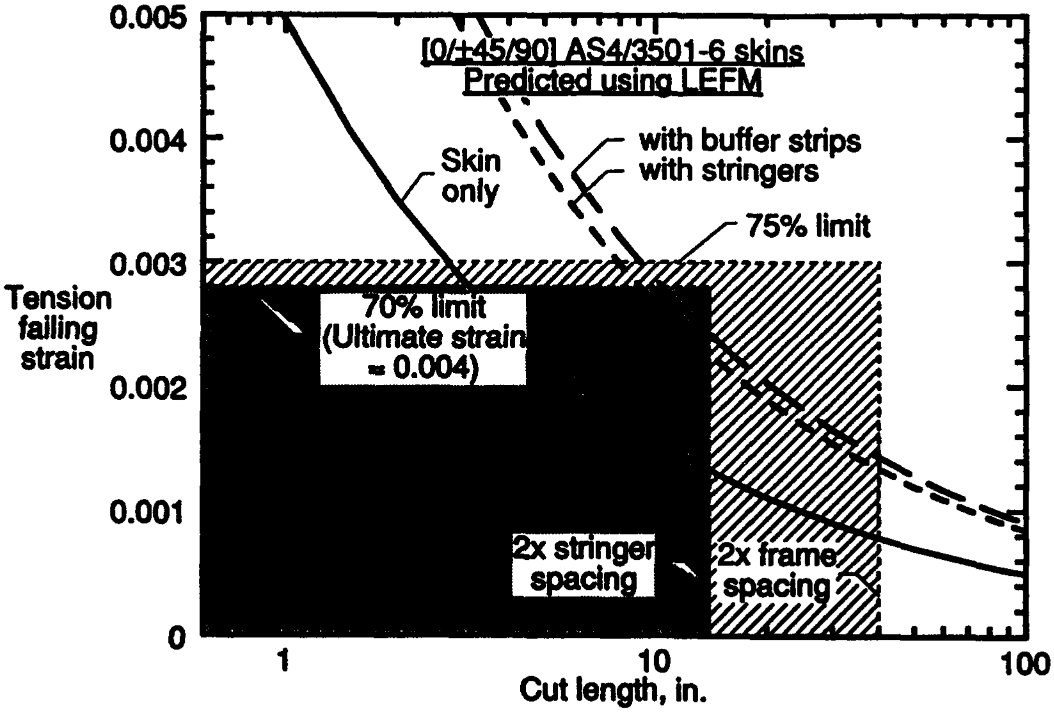
From experiments, $\gamma = 0.194$ and $\zeta_{min} = 0.345$.



FAILING STRAIN VERSUS STRINGER THICKNESS



STRENGTH FOR DISCRETE SOURCE DAMAGE



CONCLUSIONS

- ANALYSIS METHODS AND ALLOWABLES ARE REQUIRED FOR DISCRETE-SOURCE-DAMAGE CERTIFICATION
- LEFM CAN BE USED TO ACCURATELY PREDICT TENSION STRENGTH IN TERMS OF LAMINA PROPERTIES WHEN FIBERS REMAIN WELL BONDED
- LAMINATES WITH MORE THAN 15 PLY GROUPS GIVE WELL-BONDED BEHAVIOR
- LEFM IS CONSERVATIVE FOR THIN LAMINATES OF $0_i/\pm45_j/90_k$ FAMILY EXCEPT FOR $0/\pm45$ AND $0_2/\pm45$ LAMINATES
- CRACK-GROWTH-RESISTANCE (R-CURVE) METHOD CAN BE USED TO REDUCE CONSERVATISM
- STRENGTH IMPROVEMENT BY S-GLASS BUFFER STRIPS AND STRAPS CAN BE PREDICTED USING LEFM
- BENDING AND DELAMINATION OF STRAPS REDUCE STRENGTH

Best Available Copy

AEROSPATIALE AVIONS

MIL-HDBK17
MARCH 1994
MONTEREY

Study on the evolution of the dent depth due to an impact on carbon/expoxy laminates

Consequences on impact damage visibility and on in service inspection requirements for civil aircraft composite structures

by

Michèle THOMAS
composite stress office
Aerospatiale Aircraft Division France

1

AEROSPATIALE AVIONS

EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

MIL-HDBK17
MARCH 1994
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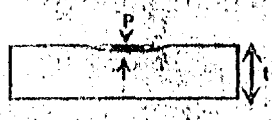
Criteria of detectability of impact damages on composite structures of civil aircraft

- The threshold of detectability for which ultimate load must be sustained depends on the type of inspection scheduled in service :
  - Walk around : only long distance visual inspection
  - Visual detailed inspection (grazing light on clean element, lens...)
  - Special detailed inspection (ultrasonic, Xray ...)
- Before mid 93, choice of Aerospatiale not to perform special detailed inspection on ATR72 and Airbus composite structures

→ Visual inspection → Visual detailed inspection to define BVID →

The threshold of visible surface indentation has been defined in 1989 by a statistical analysis supported by test results (82 panels, 1000 mesures)
- Mean value : 0.3 mm
- "A" value : 0.5 mm



Assumption of a constant dent depth through all the life of the aircraft

2

EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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MARCH 1994
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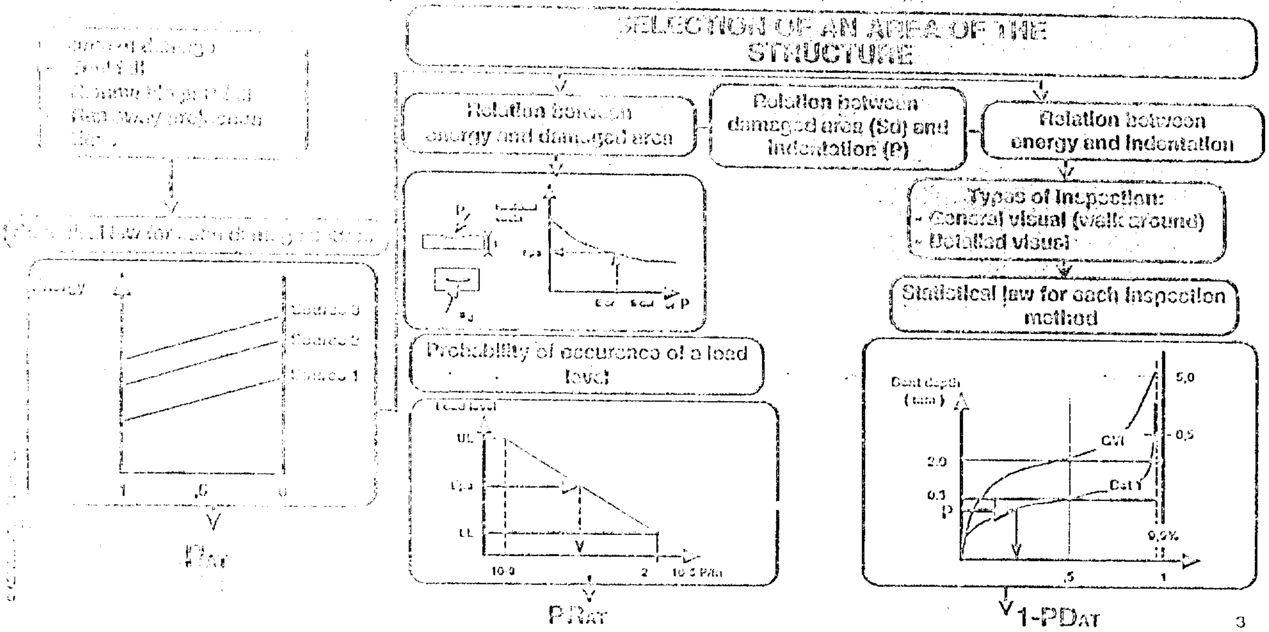
Aerospatiale method for selection of in service inspection inter vals

Deffined analysis based on the estimation of the risk of failure of a component damaged by an impact. Risk of failure = f (PAT, PRAT, 1-PDAT)
The interval inspection and check methods should be defined such that this cumulated failure risk be lower than 10^{-9} per flight hour



3

EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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AVIONS

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MARCH 1994
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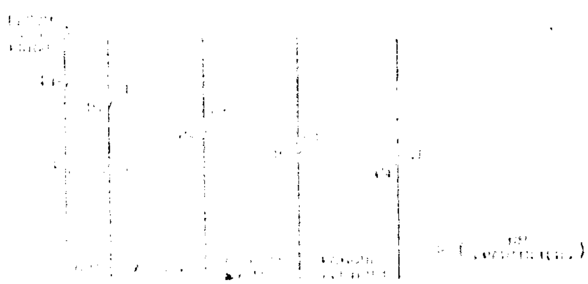
Selection of parameters having an effect on impact damage visibility on CIBA T300/914 carbone/epoxy laminates

- Time (visco-elasticity of the resin))
- Ageing (humidity)
- Thermal cycling
- Fatigue spectrum ("R" ratio σ MIN /σ MAX) and fatigue load level

Determination of the effect of these parameters on impact damage visibility
→ Individual effects : by test at coupon and subcomponent level (ATR72 wing self stiffened panel)
→ Cumulative effects of all parameters : to date by analysis



Assumption : first parameter to take into account : time. The initial indent decreases to Pi which becomes the new initial indent for the second parameter and so on.
Tests in progress on CIBA T300/914 hexcel HT/VEH25, fiberite IM7/977-2.

EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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Individual effects of time, ageing, thermal cycling and fatigue loading on impact dent depth on CIBA T300/914 laminates

Time The indent decreases in the first 24 heures after impact
Range of tested specimen thickness : 3mm to 5mm
initial indent : 0.2 mm to 2.0 mm

$\boxed{\Delta 1 = 0.20\ Pi}$

Ageing
- Specimens of 3.12 mm taken from ATR72 wing panel
- No measurements of the indents just before ageing
- Ageing : 700 hours / 1464 hours / M.C 1.7% — at 70°C / 95% R.H.
- Assumption : theoritical evolution of indent due to time Δ1 taken into account

$\boxed{\Delta 2 = 0.35\ Pi = 0.44\ P1}$

Thermal cycling
- Specimens taken from ATR72 wing panel
- Thermal cycling : 68 cycles = 40°C/+70°C

$\boxed{\Delta 3 = \text{constant} = 0.05\ mm}$

5

EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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Individual effects of time, ageing, thermal cycling and fatigue loading on impact dent depth on CIBA T300/914 laminates

Longitudinal fatigue cycling

- Level of fatigue load tested > 50% of static failure load : no influence
- Number of cycles : 100,000 cycles and 200 000 cycles
- Ratio $R = \frac{\sigma\ min}{\sigma\ max} = -1$ or 10
- Initial indent range : 0.2 mm to 1.6 mm
- Assumption : theoritical evolution of indent due to time Δ1 taken into account

	100,000 cycles	200,000 cycles
R = -1 (traction/compression)	Δ4 = 0.44 P3	Δ4 = 0.74 P3
R = 10 (compression/compression)	Δ4 = constant = 0.05mm	Δ4 = 0.325 P3

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EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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MARCH 1994
MONTEREY

Consequences of the "time evolutive BVID" on already certified primary composite structures

Material : T300/914 CIBA

Typical fatigue spectrum : 10^5 cycles, R = -10, 10% tension / 100% compression

- Cumulative effects of time, ageing, thermal cycling and fatigue loading on impact dent depth.

Residual indentation = P = (0.45 P initial - 0.10) in mm

- Initial indentation to have a remaining indent of .3 mm, threshold of visibility by visual detailed inspection

P initial = 1 mm instead of .3mm previously considered

- Use of relations between indentation, delaminated area, residual strain for T300/914 ⟹ safety margins in damage tolerance decreased by 5% ⟹ check of lowest safety margins : if insufficient new margins ⟹ new in service inspection procedures (ultrasonic method) which will insure that all damages with initial indent ≥ 0.3 mm will be detected.

7

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EVOLUTION OF DENT DEPTH DUE TO IMPACT ON CARBON/EPOXY LAMINATES

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Further work (in progress)

- Cumulative effects of all parameters for
  - Ciba T300/914
  - Hexcel HTA/EH25
  - Fiberite IM7/977-2

8

777 Empennage Program

Fastener Failures in Composite Bolted Joints

Presented by: Hui Bau, 777 Division, The Boeing Company

Requested by: Peter Shyprykevich, FAA Technical Center

To be published by:ASTM

ST1001 H. Bau
3/22/94 0/21

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Agenda

- o Bolted joints: tests vs. reality
- o Description of fastener failures in composite joints
- o Characterizing fastener failures with an equation
- o Correlation to data
- o Summary
- o Questions

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Fastener Failures in Composite Bolted Joints

Purpose

To stimulate research into the behavior of

practical bolted joints in composite materials

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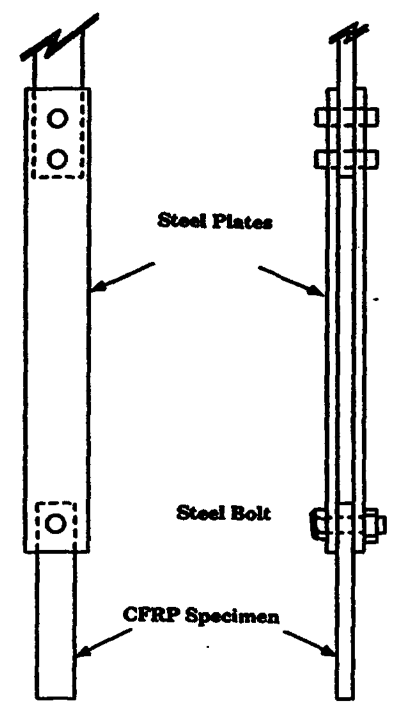

DOUBLE SHEAR BEARING TEST SET-UP

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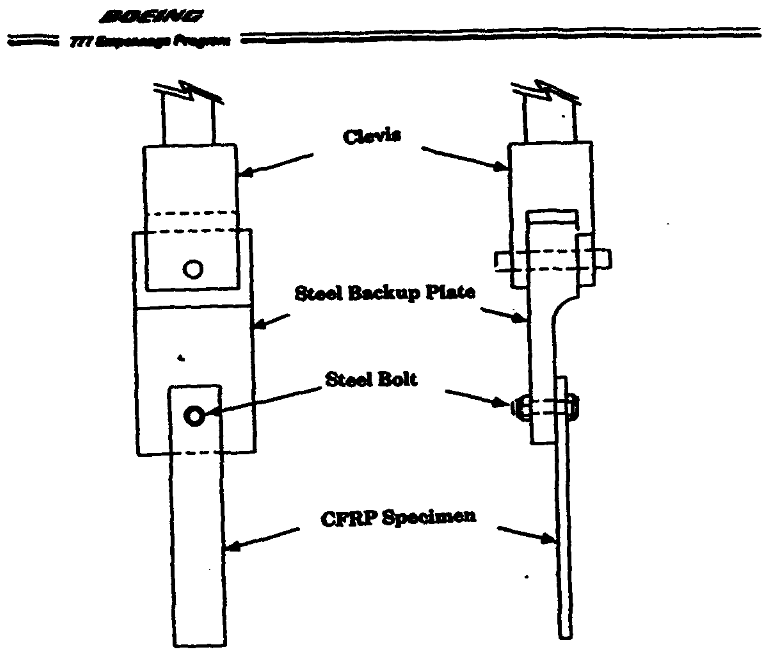
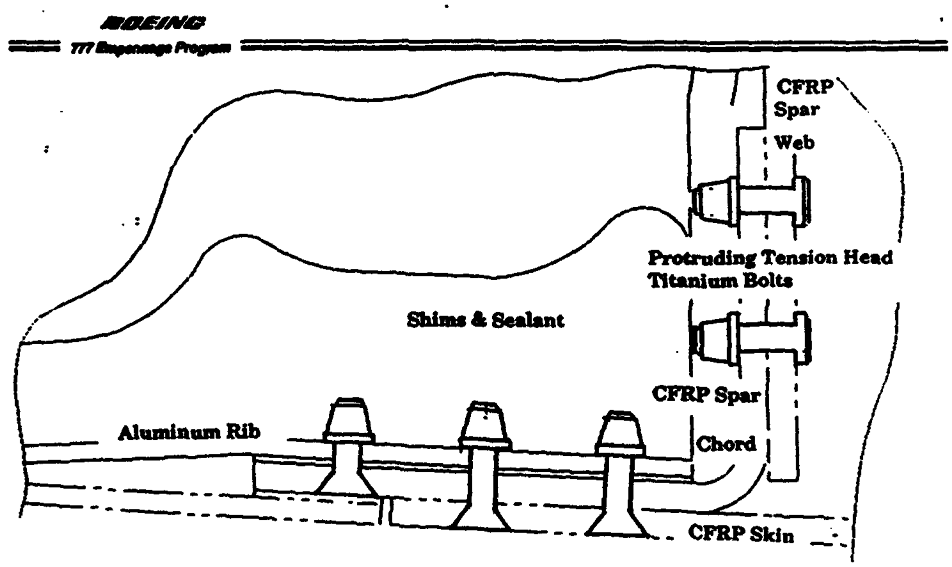
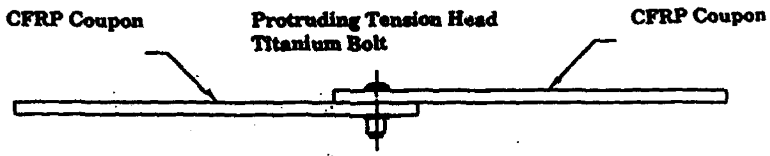


SINGLE SHEAR BEARING TEST SET-UP



Countersunk Titanium Bolt



One Fastener Stabilized Single Shear

100% Load Transfer (Bearing) Joint

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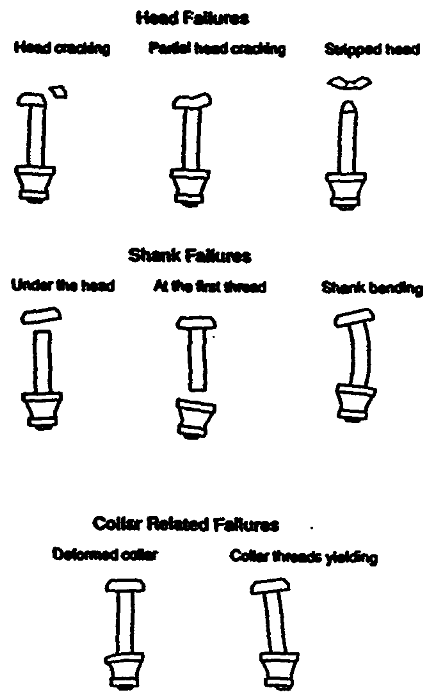

Fastener Failure Modes in Laminated Composite Bolted Joints

Figure 1

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Composite Bolted Joint Tests for Structural Allowables

Problems with using "Pure Bearing" tests for allowables

- "Pure Bearing" test values too high for design (cost)
  - Point design tests required for knockdown factors
- Potentially miss critical failure modes
  - Avoid unsafe design by conservative assumptions (weight)

Conclusions:

For design allowables, test configurations should reflect design

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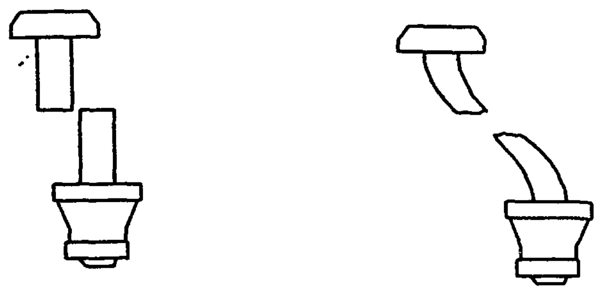
Common Fastener Failures in Metal Bolted Joints



Fastener Shear **Fastener Shear with Axial Tension**

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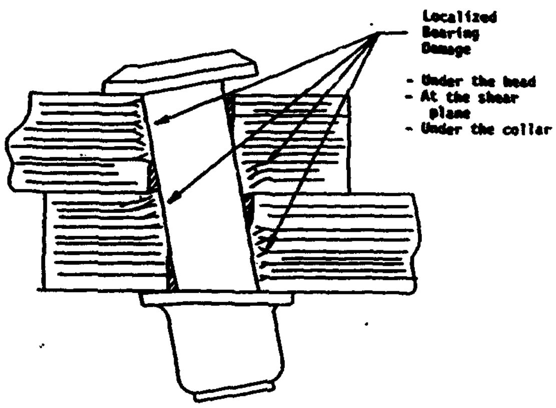

Localized Bearing Damage in Laminated
Composite Bolted Joints

Figure 2

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Fastener head style	Bolt material	Fastener failure modes in composite bolted joints
Hex or 12-point	Titanium	shank under the head shank at the first thread
Protruding tension style	Titanium	partial head cracking shank at the first thread
100° countersink tension style	Titanium	shank at the first thread
100° countersink tension style	Inconel	deformed collar
100° countersink tension style	Titanium Lockbolt	deformed collar
100° countersink shear style	Titanium	shank at the first thread partial head cracking
130° countersink reduced shear style	Titanium	head cracking

Fastener Failure Modes in Composite Bolted Joints

Table 1

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Predicted Bearing Ultimate Load

$P_{bearing} = F_{br} * d * t$

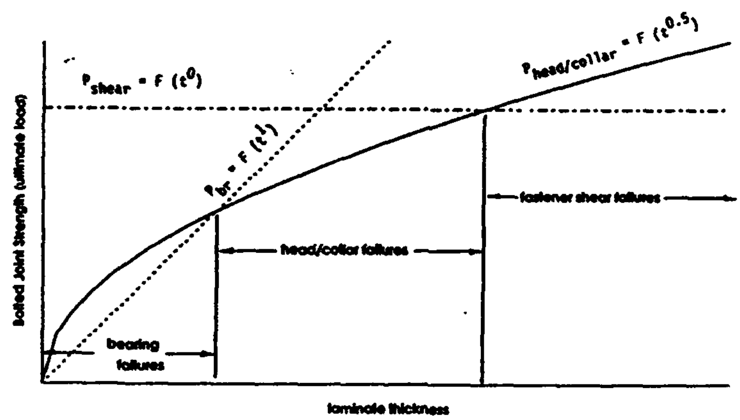
Predicted Bolt Shear Ultimate Load

$P_{shear} = F_{su} * \pi * d^2 / 4$

Head/collar failures are intermediate failure modes between laminate bearing and bolt shear

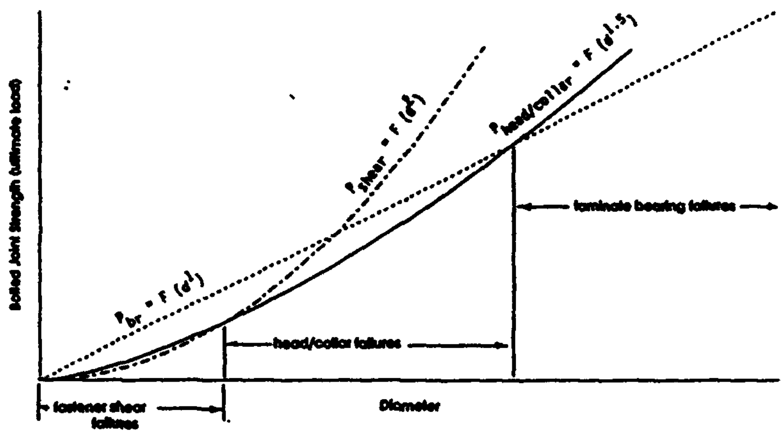
Predicted Head/Collar Ultimate Load

$P_{head/collar}$ = **intermediate function of bearing and bolt shear variables and possibly other variables**



Bolted Joint Failure Modes vs Thickness

Figure 4



Bolted Joint Failure Modes vs. Diameter

Figure 3

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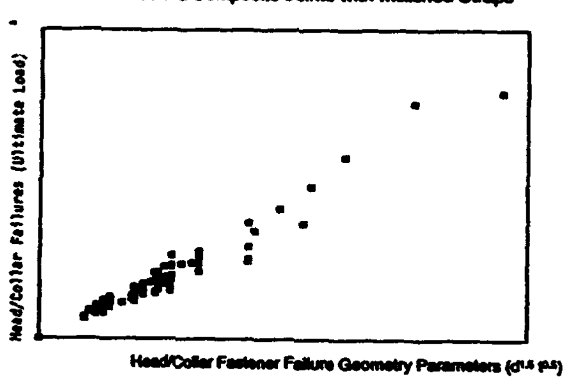
Head/Collar Fastener Failures in
Laminated Bolted Composite Joints with Matched Straps



Note: The head/collar failure loads vs. the geometry parameters ($d^{1.5} t^{0.5}$) follows a linear trend which goes through zero. This indicates that the analytical function chosen to represent the effect of geometry on head/collar fastener failures is good.

Head/Collar Failure Loads vs Geometry Parameters ($d^{1.5} t^{0.5}$)

Figure 7

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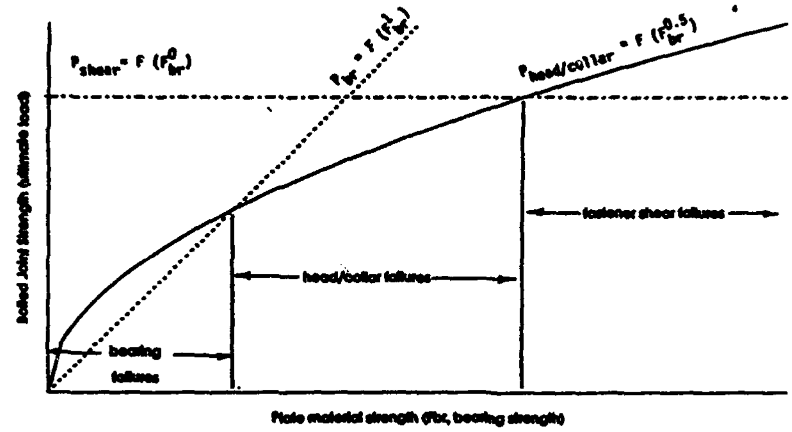

Bolted Joint Failure Modes vs. Bearing Strength (plate strength)

Figure 6

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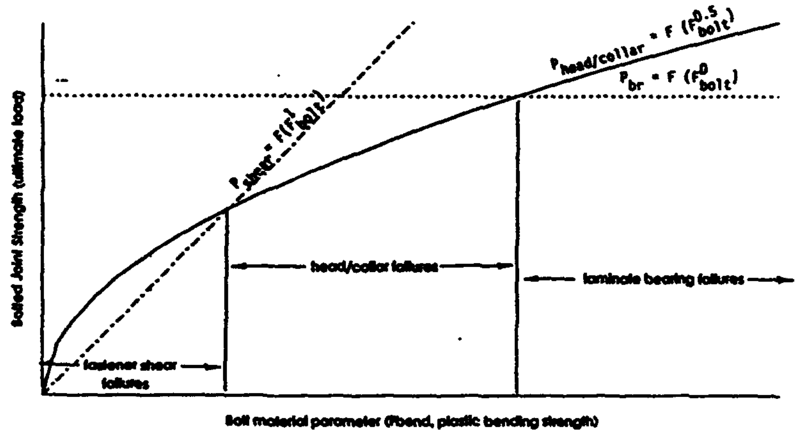

Bolted Joint Strength vs Bolt Plastic Bending Strength

Figure 5

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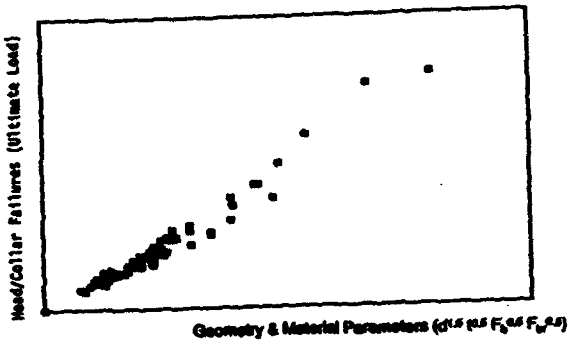
Head/Collar Fastener Failures in Laminated Bolted Composite Joints with Matched Straps



Notes:

1) The linear fit of the fastener failures vs. geometry & material is improved over the fit of fastener failures vs. geometry alone.

2) The data includes only titanium fasteners, so the accuracy of the fastener plastic bending relationship to bolt bending strength cannot be assessed. Therefore, the improve linear fit is due to the bearing strength parameter. This indicates that the bearing strength functional relationship is good.

Head/Collar Failure Load vs Geometry & Material Parameters ($d^{1.5}\,t^{0.5}\,F_b^{0.5}\,F_{br}^{0.5}$)

Figure 8

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3/22/94 18/21

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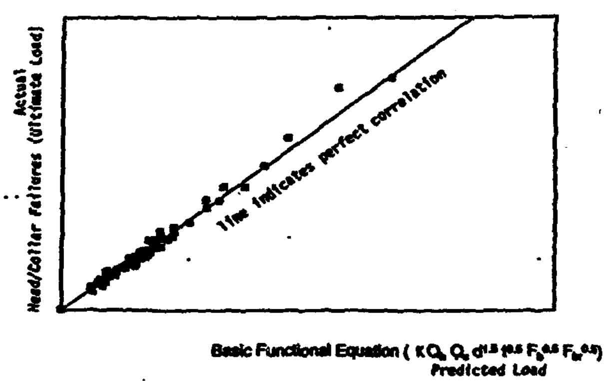
Head/Collar Fastener Failures in Laminated Bolted Composite Joints with Matched Straps



Note: *With the empirical head an... collar style factors (Qh & Qc) and empirical* correction constant (K), there is an excellent linear curve fit between head/collar fastener failure loads to the semi-empirical basic functional equation

Head/Collar Failure Loads vs Basic Functional Equation ($K Q_h Q_c d^{1.5}\,t^{0.5}\,F_b^{0.5}\,F_{br}^{0.5}$)

Figure 9

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3/22/94 19/21

Characterized fastener failures for simple bolted joints:

- **CFRP/CFRP joints with identical straps**
- **Static tension loading**
- **Boeing 777 program bearing and fastener allowables**

To develop a method of analysis for design, consider:

- **Joint configuration variables**
  different strap thicknesses, materials, multiple straps, etc.
- **Loading condition variables**
  bolt axial tension, bypass loads, compression, etc
- **Clamp-up, shims, sealant, environment, hole tolerance, etc.**
- **Accurate material properties = Good correlation**

Summary

To generate design allowables;

- **Test configurations should reflect design**
- **Account for all major failure modes (by analysis or conservatism)**

Composite bolted joints

- **Fastener failures are critical for certain composite bolted joints**
- **This paper characterizes fastener failure strength for simple joints**
- **More composite bolted joints research is necessary**

Method for solving a bounded problem

6. MIL-HDBK-17 OUTLINE AND PROGRESS REPORT

Abbreviations:

Status

- I Approved by Coordination Group
- d Draft
- m Modification of previously approved document underway
- r Under review by Coordination Group
- =1 Same as Volume 1

Working Group

- B Braiding
- D Data Review
- F Filament Winding
- G Guidelines
- H Thick Section Composites
- J Structural Joints
- M Materials & Processes
- R Supportability
- S Statistics
- T Testing
- X/Y X writes with review by Y
- X-Y X and Y share responsibility

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1.3	Scope	I	G
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1.5	Approval Procedures	I	G
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2.2.6	Test Method Acceptance Criteria	I	G
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2.5	Filament Wound Materials Property Tests	I	F/G
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2.7	Thick-Section Composites Property Tests		H/G
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Proceedings, Twenty-Ninth MIL-HDBK-17 Coordination Group Meeting

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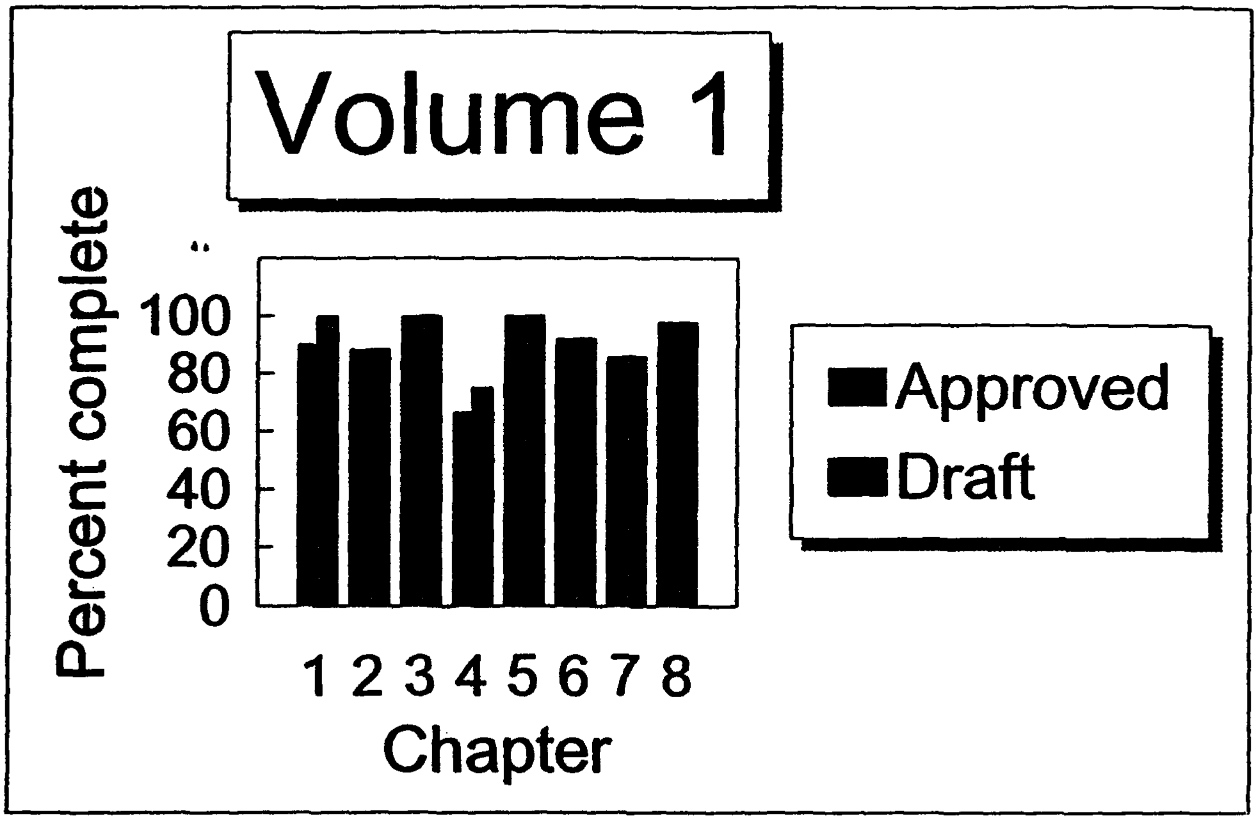
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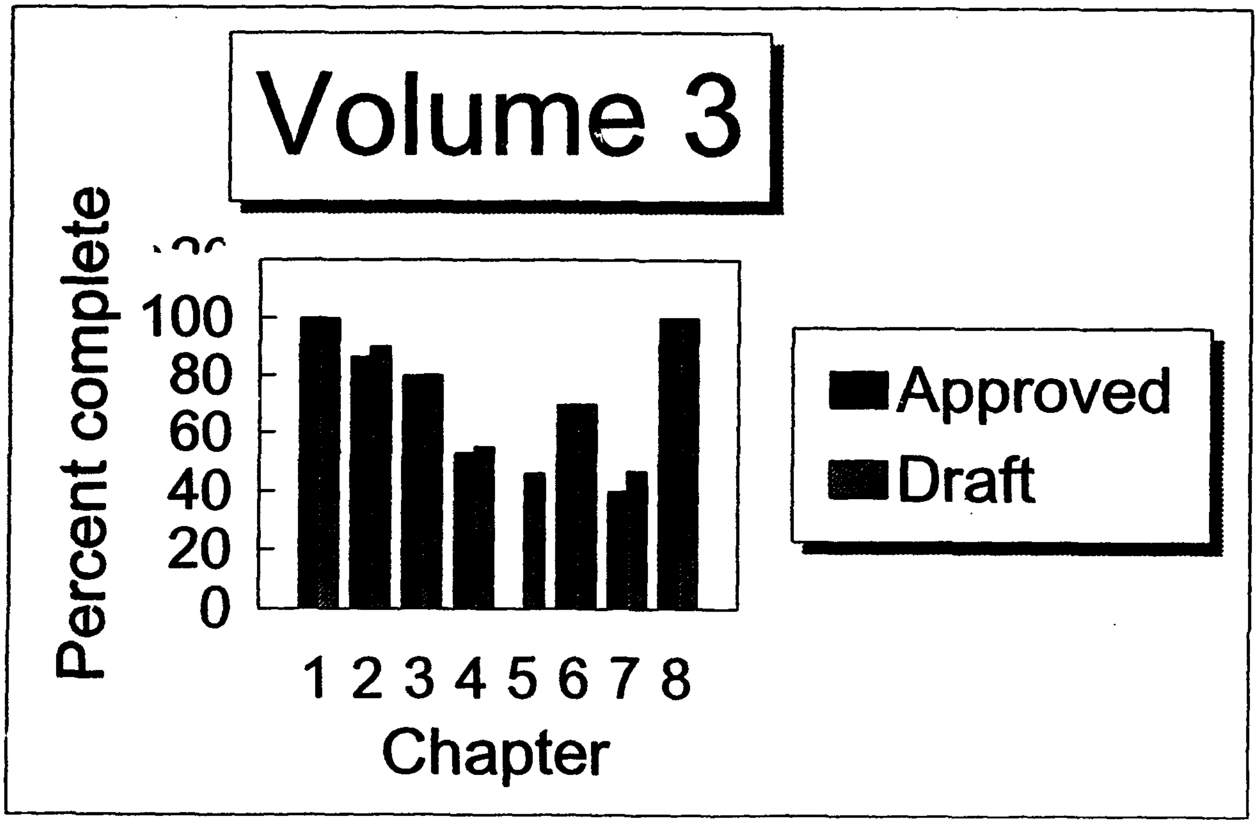
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Data Analysis/Review

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Received	49	5	1	2	4	2	1	1	1
Approved	16 +2	4	-	1	1	-	-	1	-
Pooling	14*								
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* Including 3 approved

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